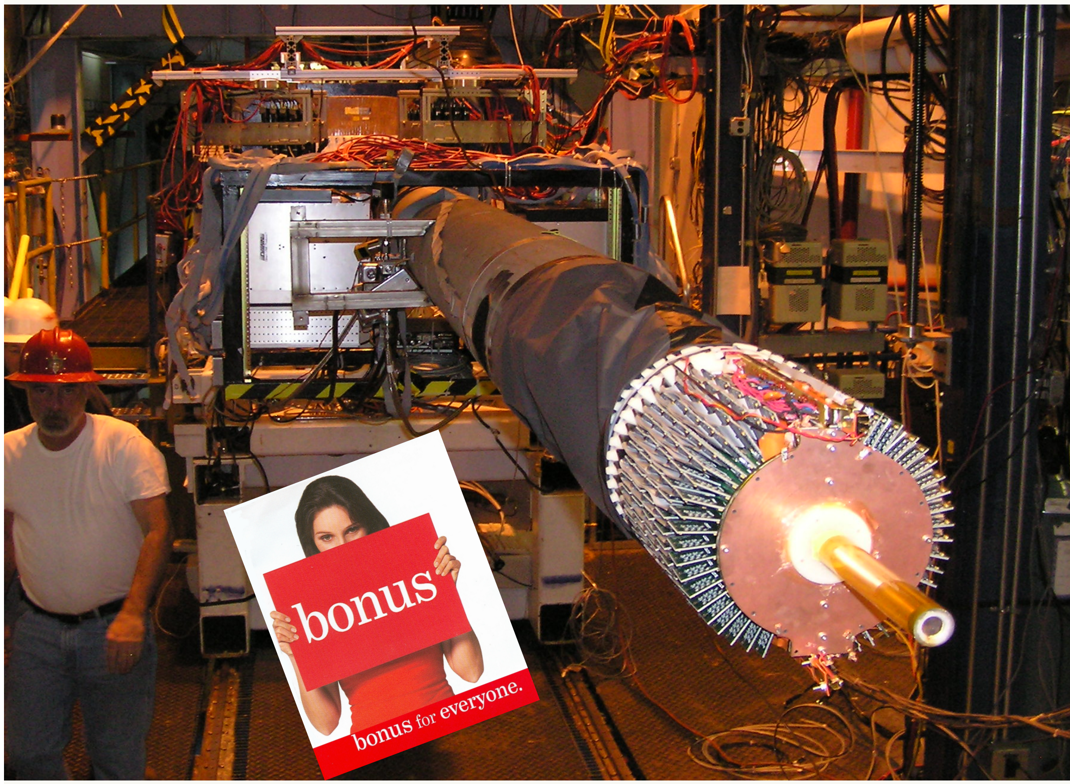
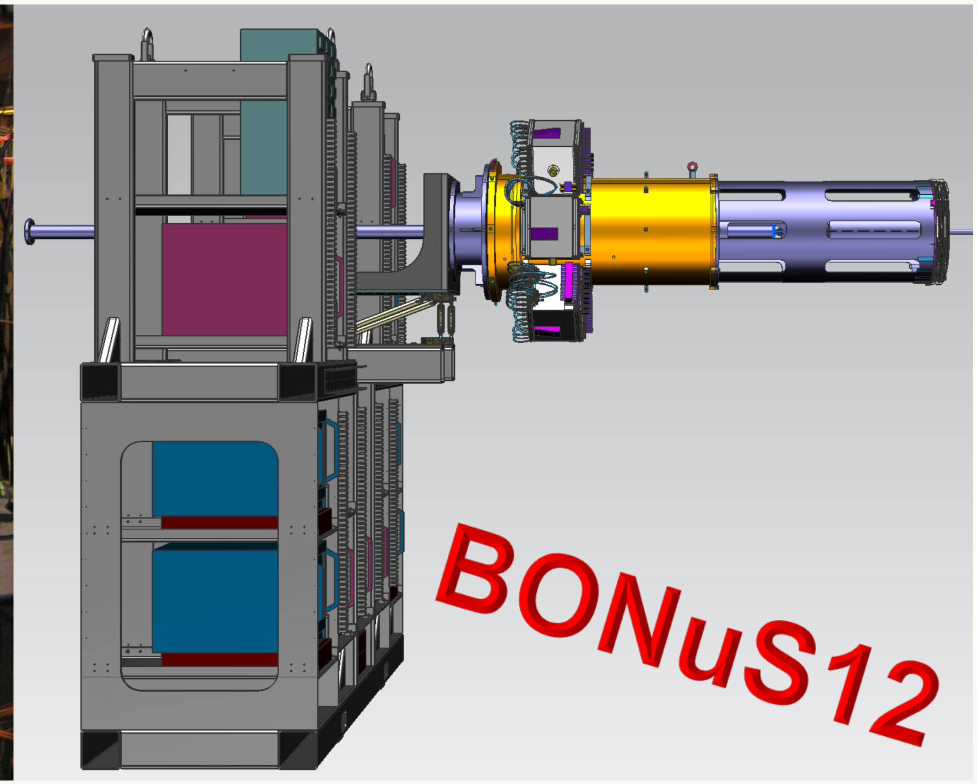
The BONuS measurements of the free neutron structure function

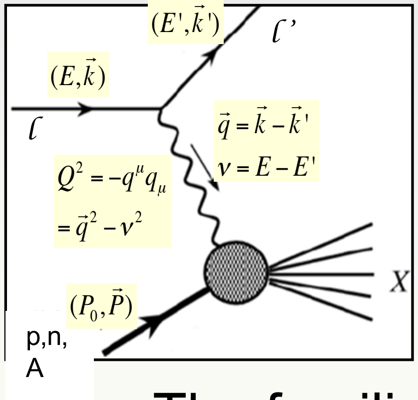




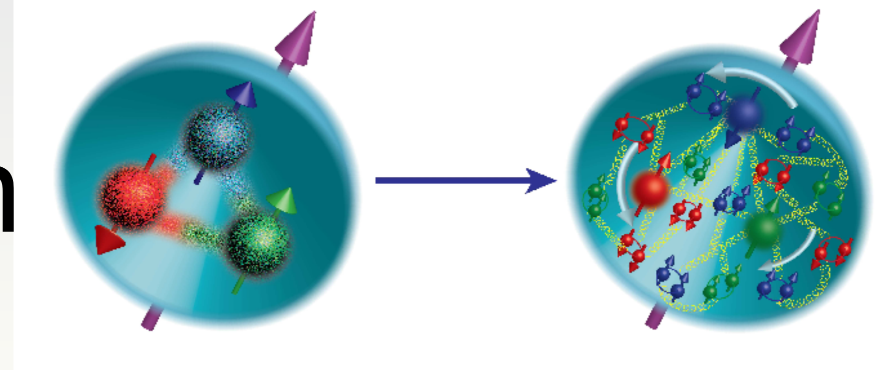
Sebastian Kuhn
Old Dominion University

Overview

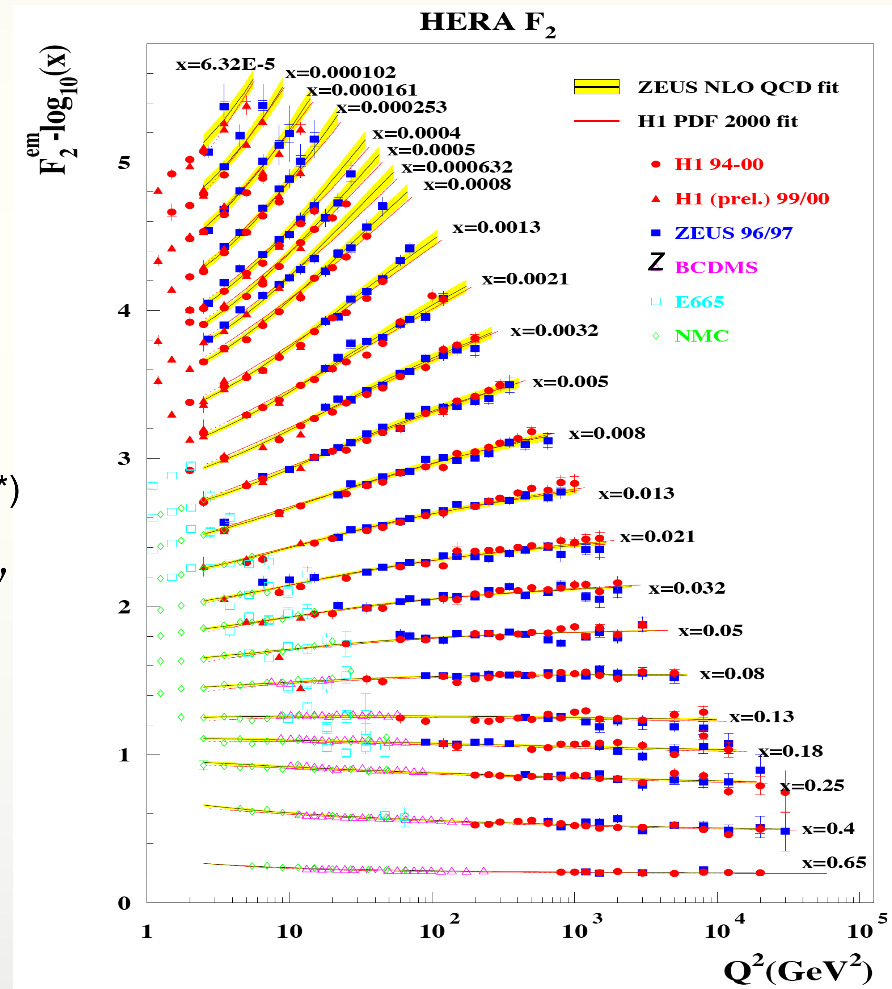
- Neutron Structure Functions (esp. at large x) - Why?
- The Neutron - No Free ~~Lunch~~ Target
  (Nucleon structure modifications in Nuclei)
- Spectator Tagging
  (Principle and Experimental Realization - the RTPC)
- The “BONuS” experiment
- New recoil detectors
- The (11 GeV) Future of “BONuS”
- Conclusion and Outlook



Introduction



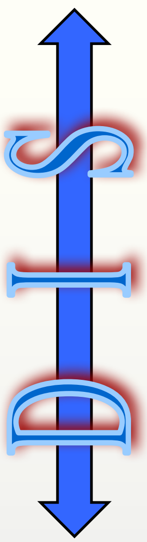
- The familiar (?) 1D world of Nucleon longitudinal structure:
  - Take a nucleon
  - Move it real fast along z
    $\Rightarrow$ light cone momentum
    $P_+ = P_0 + P_z$ (>>M)
  - Hit a "parton" (q, g,…) inside
  - Measure **its** l.c. momentum
    $p_+ = p_0 + p_z$ (m≈0)
  - $\Rightarrow$ Momentum Fraction $\xi = p_+ / P_+$ *)
  - In DIS: $\xi = (q_z - \nu)/M \approx x_{Bj} = Q^2/2M\nu$
  - Probability: $F_1(x) = \frac{1}{2}\sum_i e_i^2 q_i(x)$
  - Because of spin-1/2: 2nd SF F_2(x)



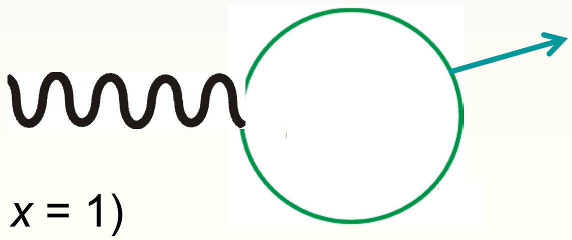
*) Advantage: Boost-independent

⇒ Our 1D View of the Nucleon

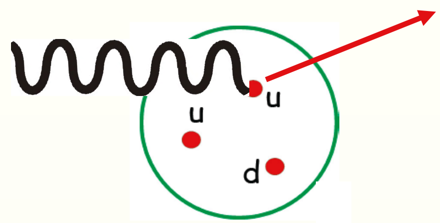
(also depends on the resolution of the virtual photon ~ $1/Q^2$



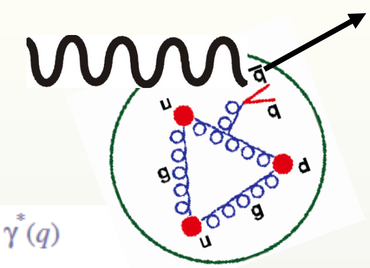
- Elastic scattering
  (Whole system recoils, $x = 1$)



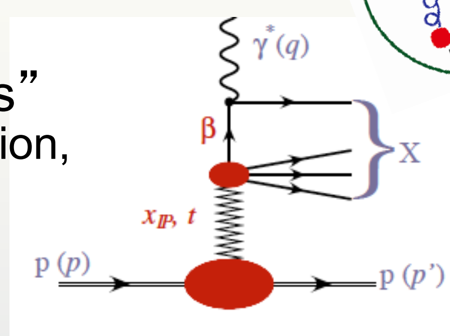
- Resonances
  ($x < 1$, $W < 2$ GeV)

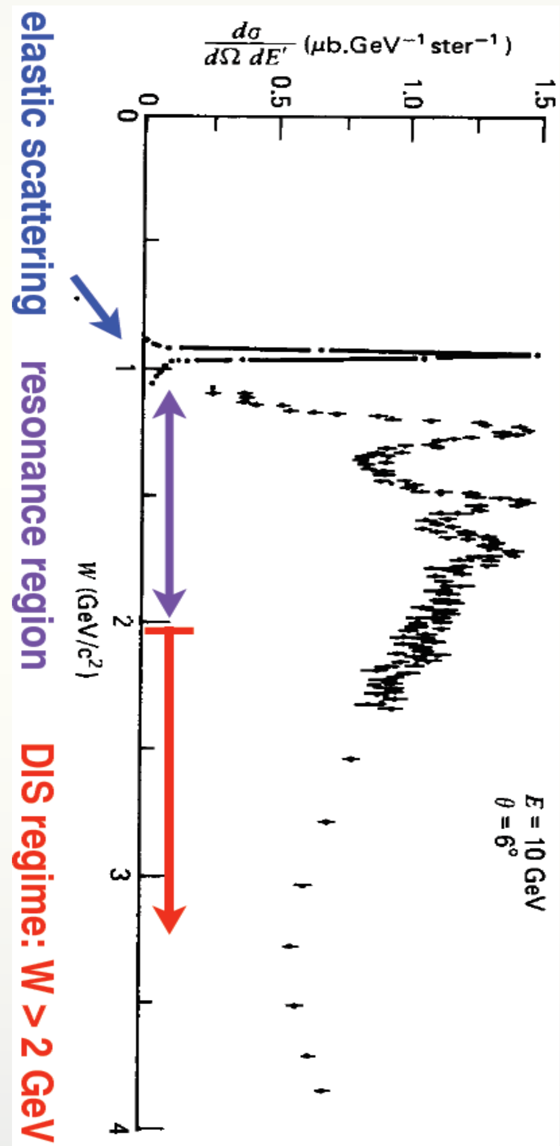


- Valence quarks
  ($x \approx 0.3 - 0.9$, $W > 2$ GeV)
- Sea quarks, gluons
  ($x < 0.3$)



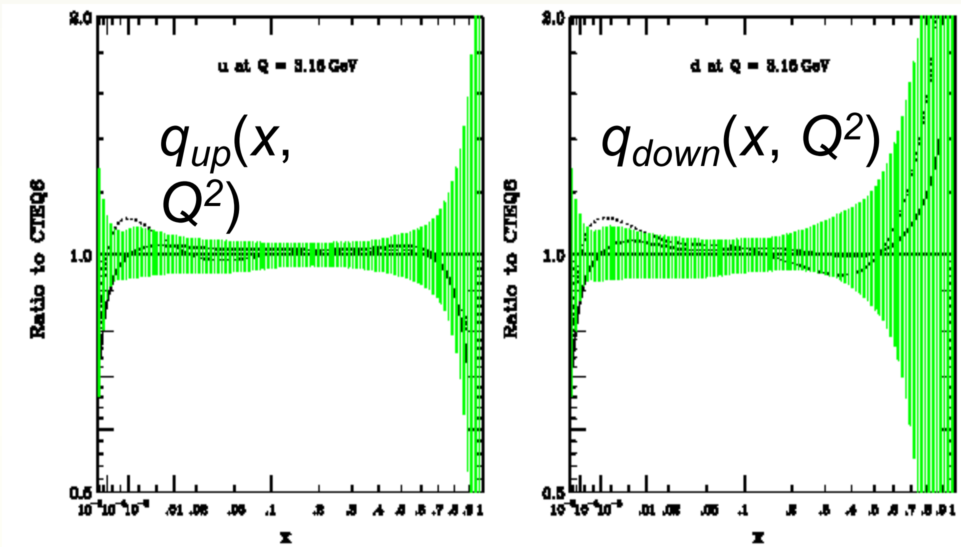
- "Wee Partons"
  ($x \to 0$, Diffraction,
  Pomerons)



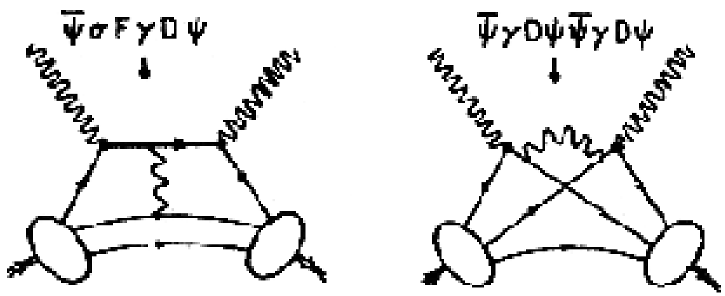


Structure Functions and Moments: Why large x?

$$\frac{d\sigma}{d\Omega dE'} = \sigma_{Mott}\left(\frac{F_2(x)}{\nu} + 2\tan^2\frac{\theta_e}{2}\frac{F_1(x)}{M}\right); \quad F_2(x,Q^2) = x \sum_{f=up,down,\ldots} z_f^2\left(q_f(x,Q^2) + \bar{q}_f(x,Q^2)\right)$$



$\tau = 4$



- $q_{down}/q_{up}(x\to1)$ is a crucial test of valence quark models
  - SU(6) breaking, pQCD, DSE,…
- Precise PDFs at large *x* needed as input for LHC, ν experiments etc.
  - Large *x*, medium Q^2 evolves to medium *x*, large Q^2
  - Also: NUCLEAR structure functions
- Moments can be directly compared with OPE (twist expansion), Lattice QCD and Sum Rules
  - All higher moments are weighted towards large *x*
- Quark-Hadron Duality

$$M_n^{CN}(Q^2) = \int_0^\infty dx x^{(n-2)} F_2(x,Q^2) = \sum_{\tau=2k}^{\infty} E_{n\tau}(\mu,Q^2) O_{n\tau}(\mu)\left(\frac{\mu^2}{Q^2}\right)^{\frac{1}{2}(\tau-2)}$$ + TM corr.

Why neutron? d(x) and u(x) as x $\rightarrow$ 1

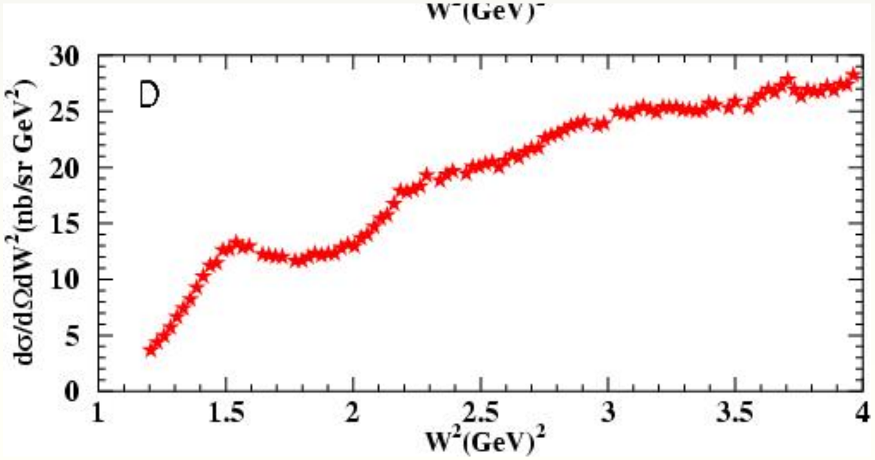
- Valence structure of the nucleon - sea quarks and gluons don't contribute
- SU(6)-symmetric wave function of the proton in the quark model:

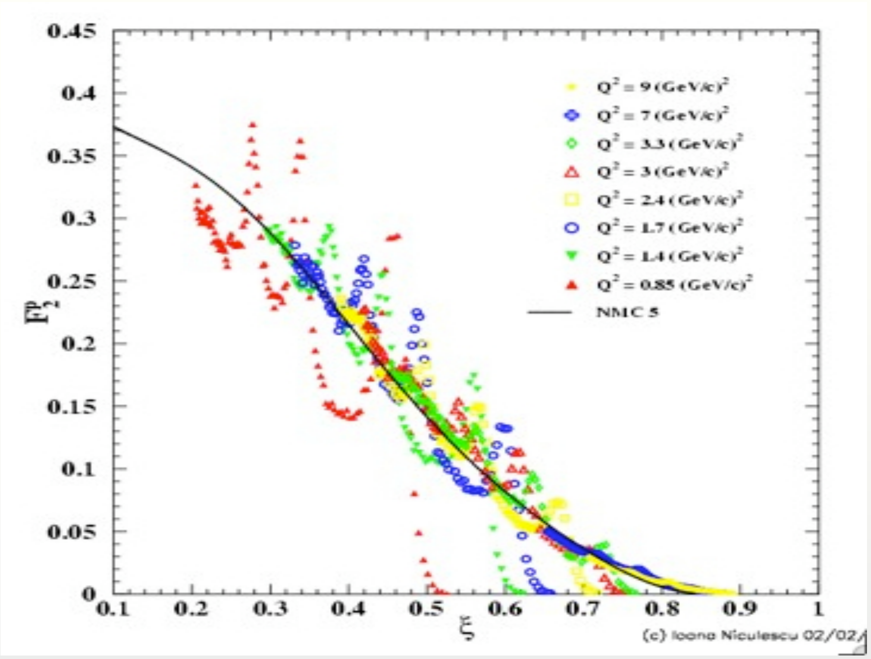
$$|p\Uparrow\rangle = \frac{1}{\sqrt{18}}\left(3u\uparrow[ud]_{S=0} + u\uparrow[ud]_{S=1} - \sqrt{2}u\downarrow[ud]_{S=1} - \sqrt{2}d\uparrow[uu]_{S=1} - 2d\downarrow[uu]_{S=1}\right)$$

- In this model: d/u = 1/2, Δu/u$^{*)}$ = 2/3, Δd/d = -1/3 for all *x*
- Relativistic quark model: quark helicities reduced, orbital angular momentum introduced
- Hyperfine structure effect (1-gluon exchange): S=1 suppressed for small spectator pair mass $\Rightarrow$ d/u = 0, Δu/u = 1, Δd/d = -1/3 for $x \rightarrow 1$
- pQCD: helicity conservation (q$\uparrow\uparrow$p) $\Rightarrow$
  d/u =2/(9+1) = 1/5, Δu/u = 1, Δd/d = 1 for $x \rightarrow 1$
- Wave function of the neutron via isospin rotation:
  replace u $\rightarrow$ d and d $\rightarrow$ u => using experiments with protons and neutrons one can extract information on u, d, Δu and Δd in the valence quark region.

$^{*)}$ spin dependent quark density $\Delta q = (q\uparrow - q\downarrow)$ for Nucleon N$\Uparrow$

Structure Functions and Resonances





- Precise structure functions in Resonance Region constrain nucleon models
  [Separate resonant from non-resonant background; isospin decomposition]
- Needed as input for spin structure function data, radiative corrections,…
- Compare with DIS structure functions to test duality

Present Knowledge of d/u ($x \to 1$)

Assuming charge independence

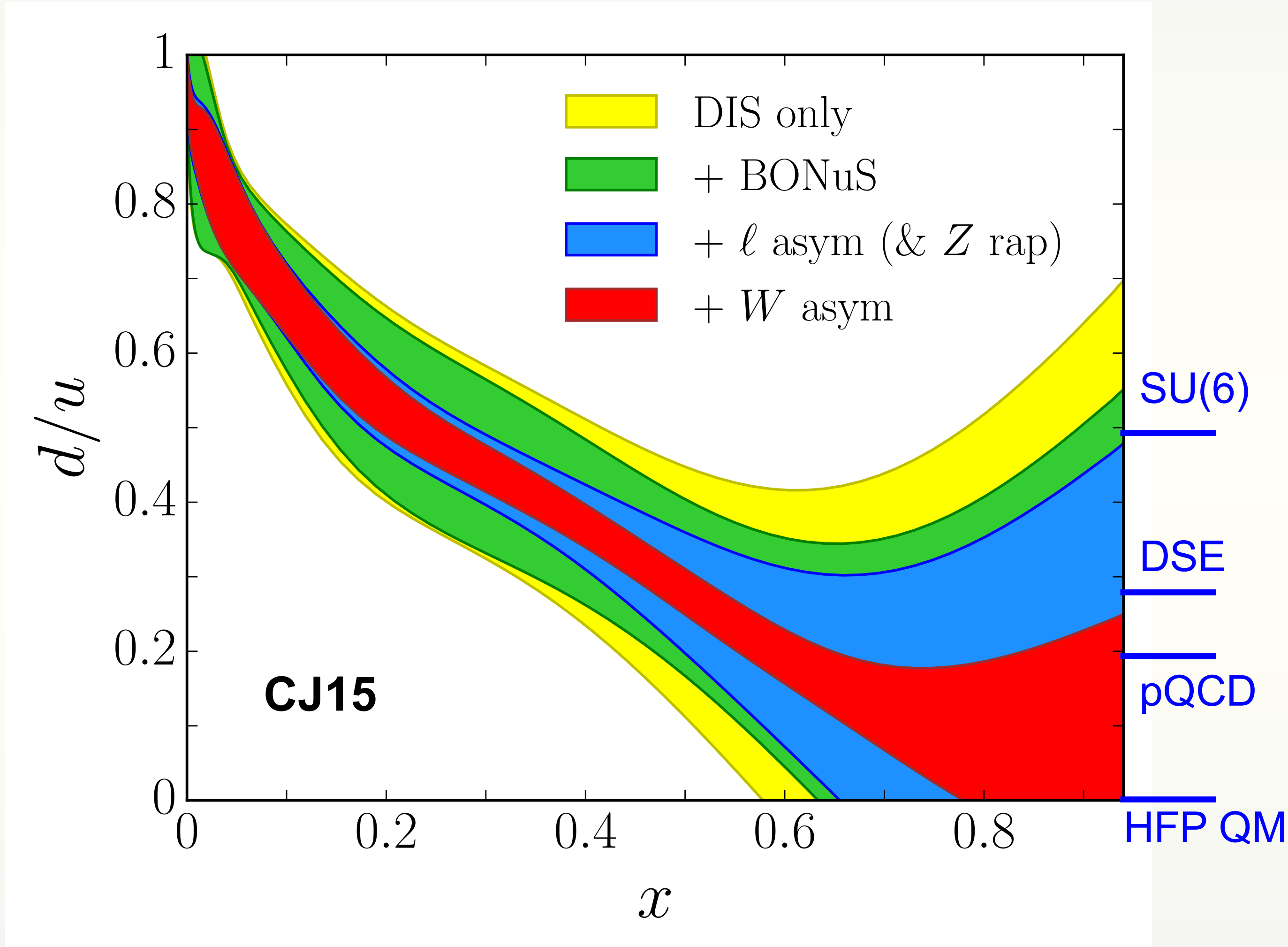
(= invariance under 180° rotations in isospin space):

$$\frac{F_{2n}}{F_{2p}} \approx \frac{1+4d/u}{4+d/u} \Rightarrow$$

$$\frac{d}{u} \approx \frac{4F_{2n}/F_{2p}-1}{4-F_{2n}/F_{2p}}$$

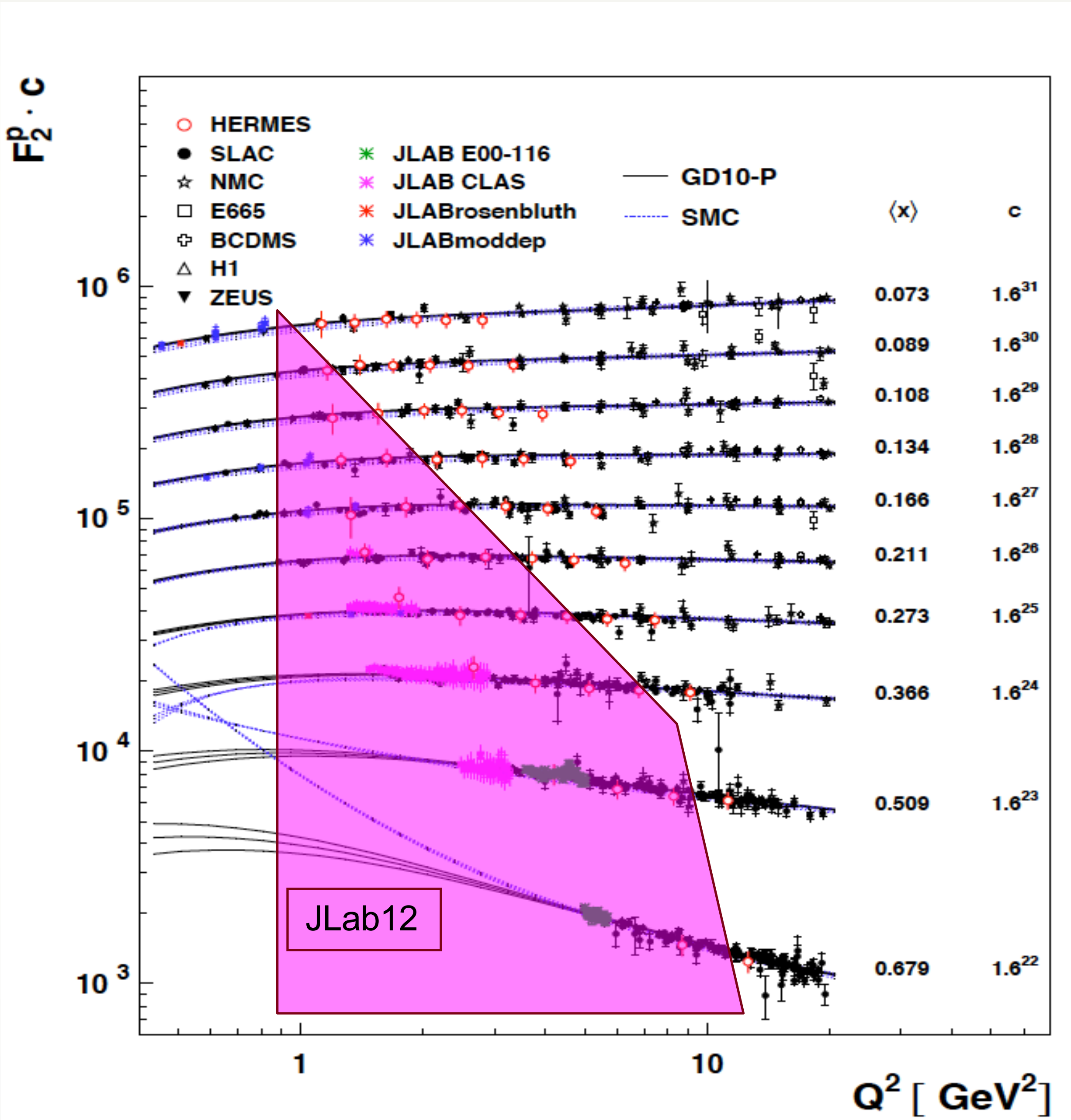
$$F_{2n}/F_{2p} = F_{2d}/F_{2p} - 1$$

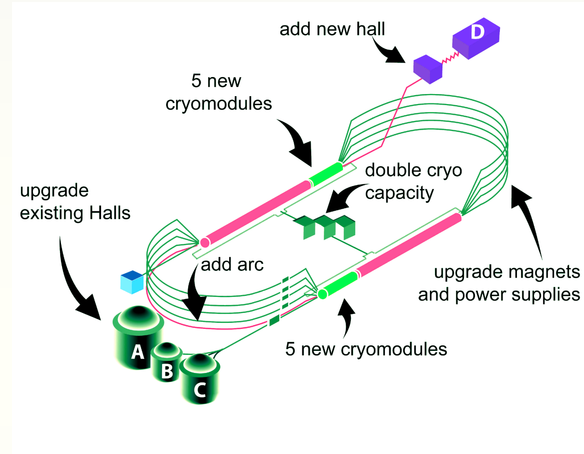
???



- Neutron data limited by “Nuclear Binding Uncertainties”

Jefferson Lab in Context





NOW: 12 GeV

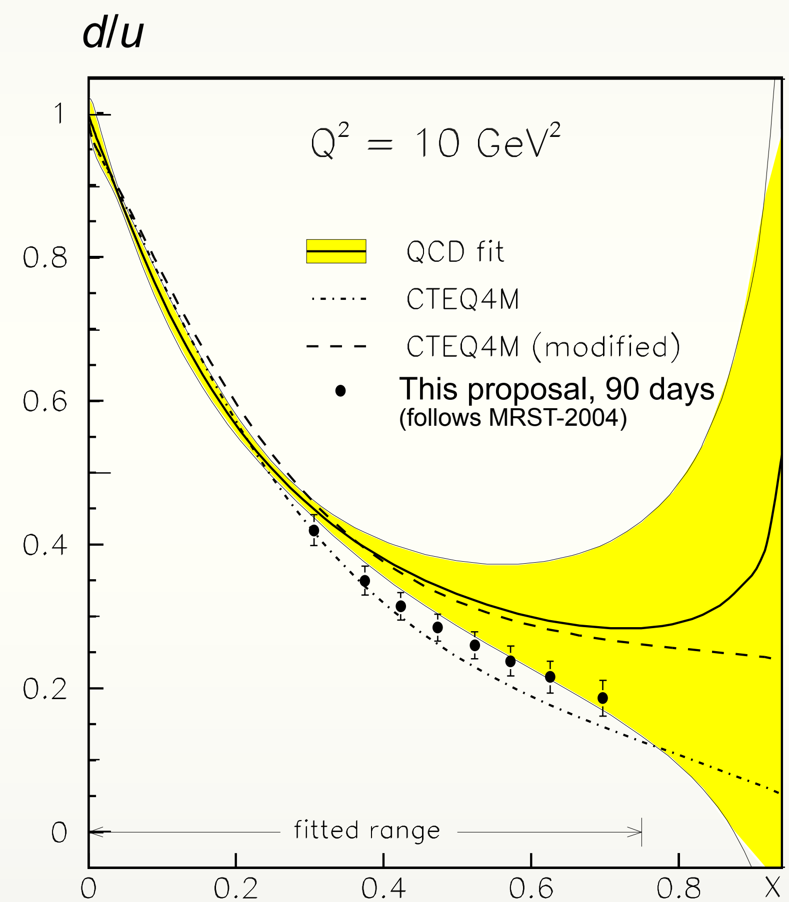
$Q^2 = 1\ldots13\ \text{GeV}^2$

$x = 0.06\ldots0.8$

$W = 0.94\ldots4$ GeV

Cleanest way to access *d/u*

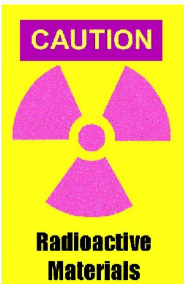
- Exploit different "charge" ratios for weak and electromagnetic interaction.
- Possible processes: W/Z production, neutrino → muon scattering, parity-violating lepton scattering (PV DIS).
- Advantage: Direct measurement on the proton; does not require assumptions about charge symmetry.
- Limitations in statistical precision.



PV DIS on p target, 90 days with SoLID. E12-10-007 in Jefferson Lab's Hall A, approved with A rating. Awaiting funding…

Neutron Data Are Important…
…but hard to get

- Free neutrons decay in 15 min.



- Radioactivity!

- Zero charge makes it difficult to create a dense target

Magnetic bottle: 10^3 - 10^4 n/cm^2 [TU München]

Typical proton target: $4{\cdot}10^{23}$ p/cm^2 [10 cm LH] – 10^{14} p/cm^2 [HERMES]

An Underground Nuclear Explosion as a Polarized Neutron Source

G. A. Keyworth and J. R. Lemley

Polarization Phenomena in Nuclear Reactions Proceedings (1970)

"Although an underground nuclear explosion is not the most conventional neutron source, it offers definite advantages…"

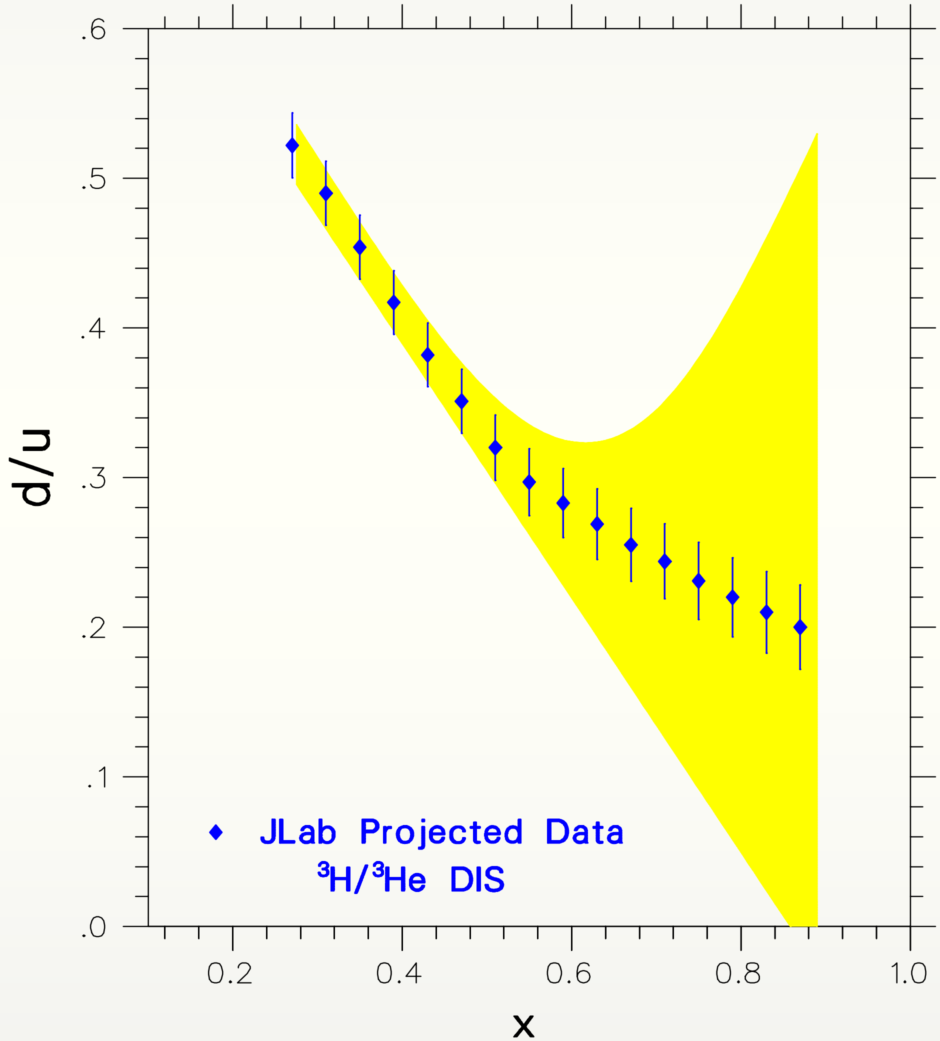
- => Alternative Solution: Deuterons, Tritons and Helium-3…

BUT: Nuclear Model Uncertainties:

Fermi motion, off-shell effects (binding), structure modifications (EMC effect), extra pions/Deltas, coherent effects, 6-quark bags…

One Solution: take ratio of nearly identical nuclei -> EMC effect largely cancels *)

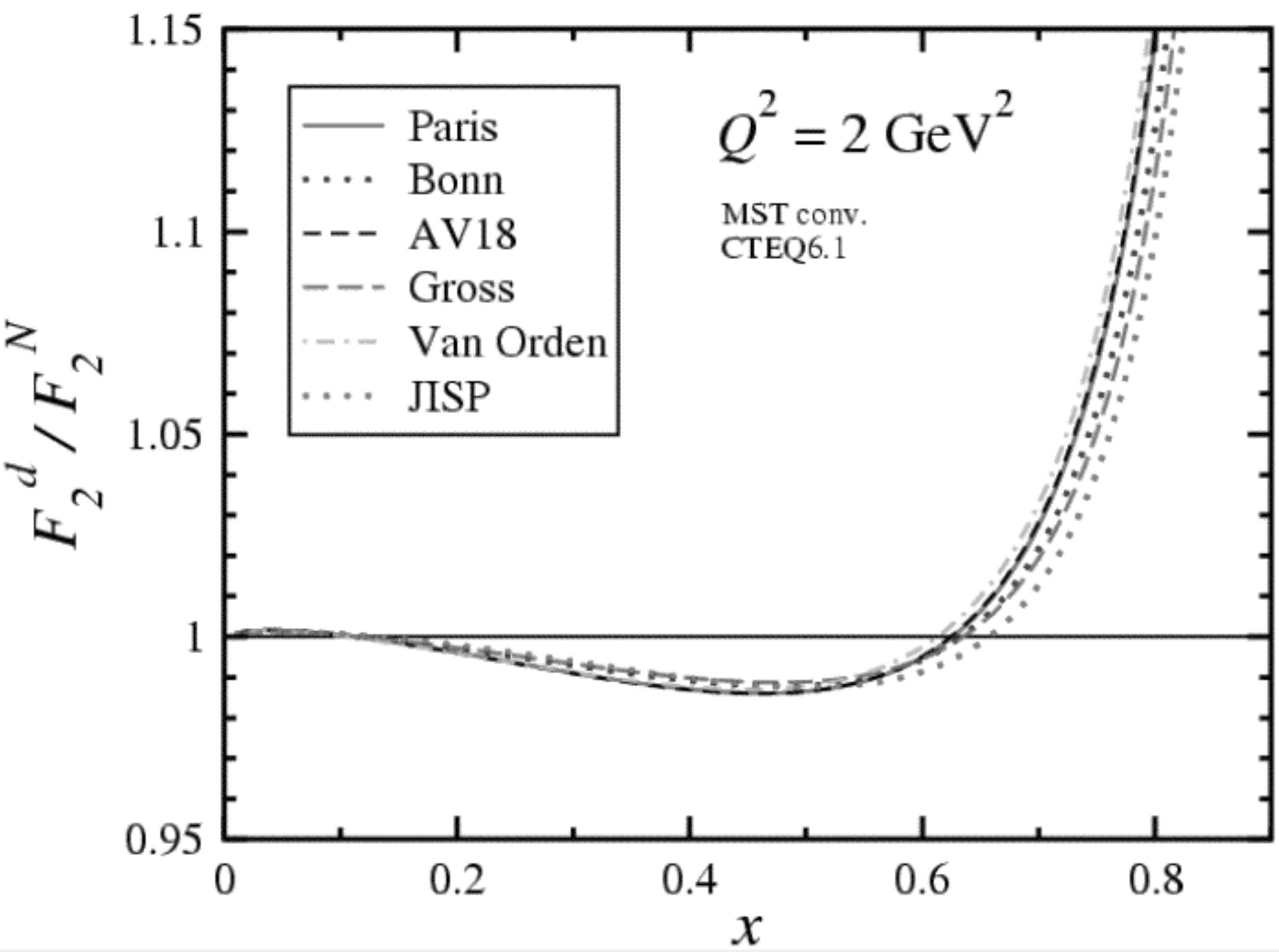
- Best case: Isospin doublet ^{3}He/^{3}H.
- $$\frac{F_2^{^3H}(x)}{F_2^{^3He}(x)} = \frac{\left(\frac{4}{9}+2\frac{1}{9}\right)u(x)+\left(\frac{1}{9}+2\frac{4}{9}\right)d(x)}{\left(2\frac{4}{9}+\frac{1}{9}\right)u(x)+\left(2\frac{1}{9}+\frac{4}{9}\right)d(x)} = \frac{\frac{2}{3}+d(x)/u(x)}{1+\frac{2}{3}d(x)/u(x)}$$
- Several experiments with tritium target planned for 2017 in Jefferson Lab's Hall A



*) But still measuring smeared SF, including smeared quasi-elastic!

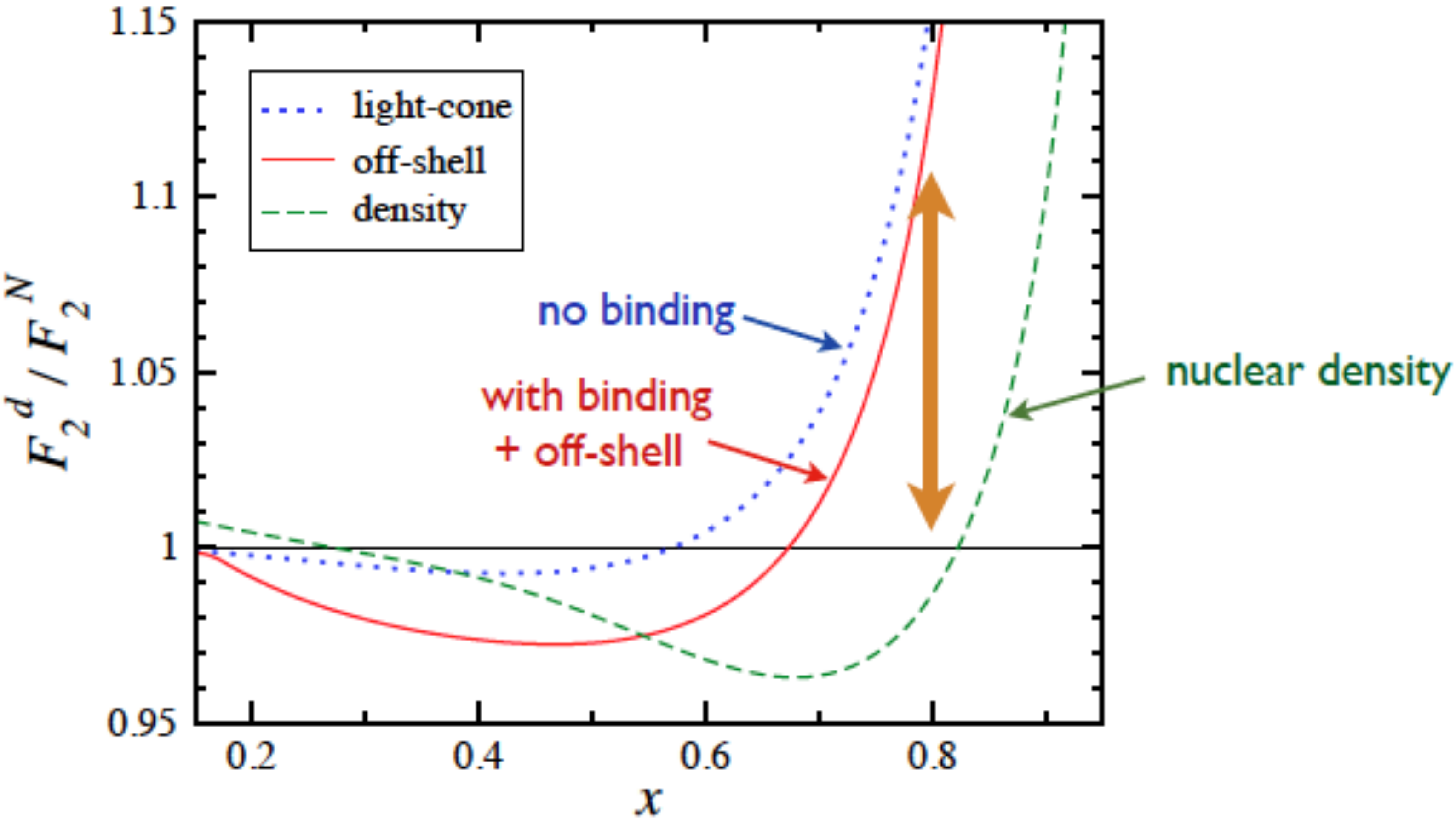
"Marathon" Experiment in Hall A. W > 1.8 GeV.
Experiment E12-10-103 42d, A rating, * from PAC41.
Scheduled to run (partially?) Fall/Winter 2017-18

Inclusive scattering on D: Large *x* - Large Nuclear Effects



- Even simple "Fermi Smearing" leads to significant dependence on D wave function
- Different models for off-shell and "EMC" effects lead to large additional variations
- Contributions from MEC, Δ(1232) and "exotic" degrees of freedom unknown
- FSI?

EMC effect in deuteron

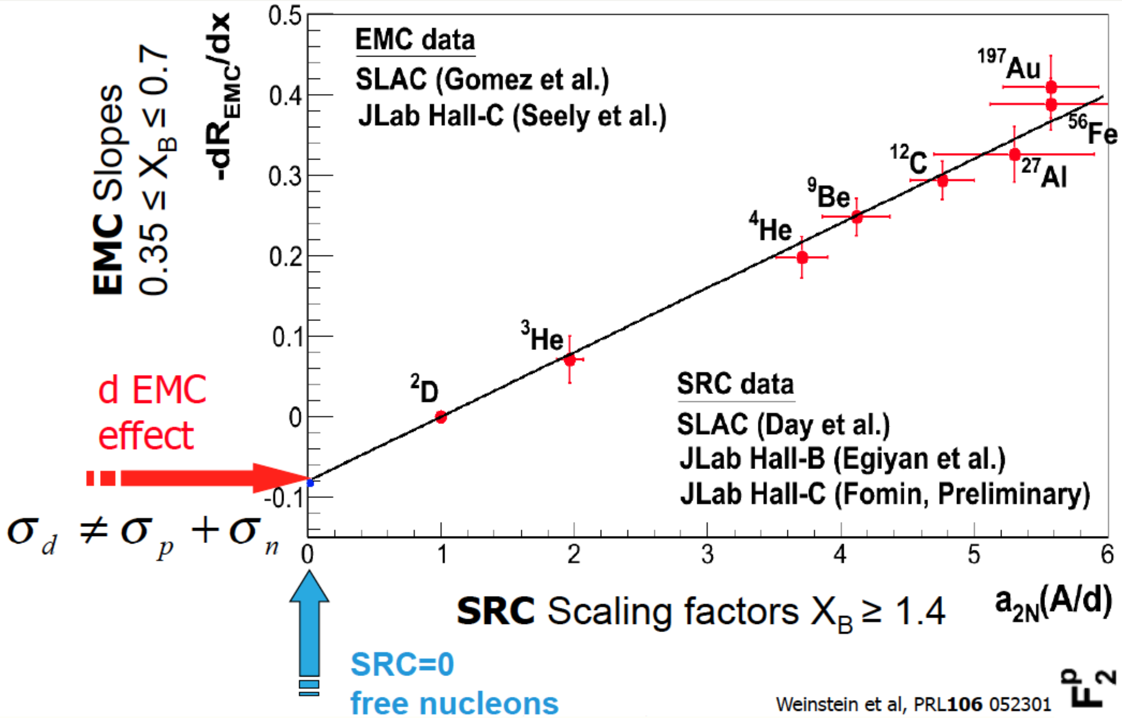


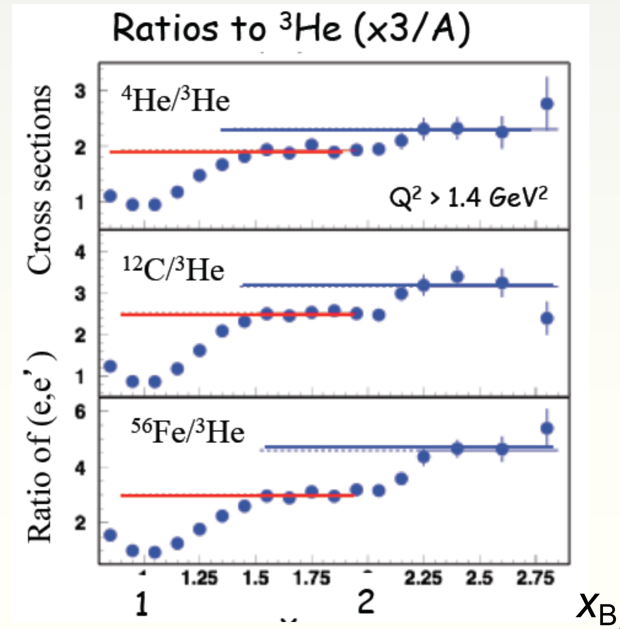
→ using off-shell model, will get *larger* neutron *cf. light-cone* model

→ but will get *smaller* neutron *cf. no nuclear effects* or *density* model

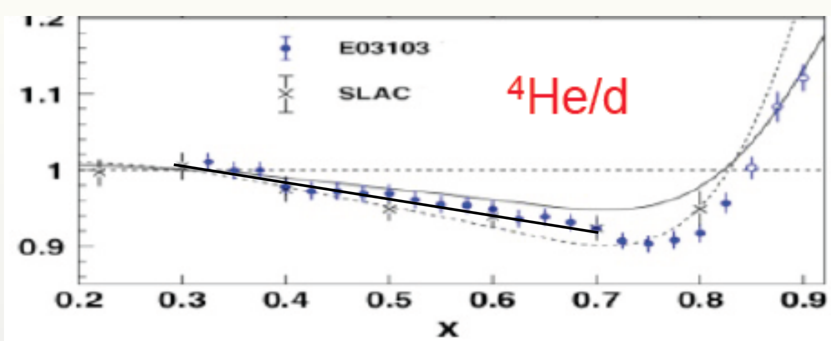
Estimating the EMC effect in Deuterium

L. Weinstein, E.I. Piasetzky, D. Higinbotham, J. Gomez, O. Hen and R. Shneor, PRL106 052301 (2011)

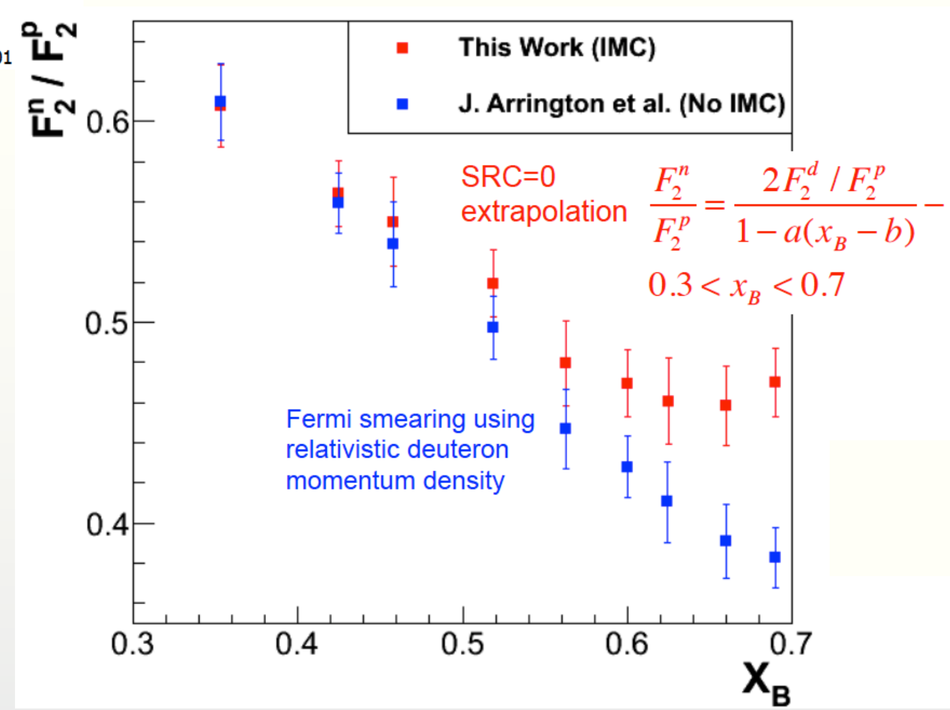




Probability of a nucleon inside the nucleus to be in a "short-range" (tensor) correlation (dominated by pn correlations 10:1)



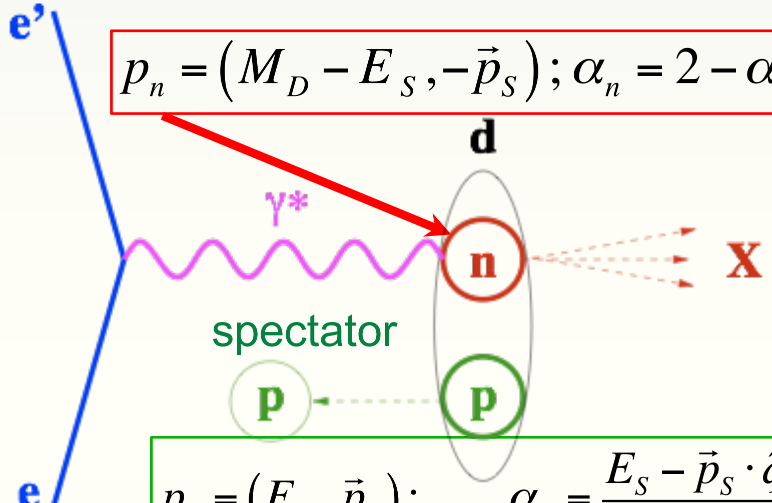
J. Seely, PRL 103, 202301 (2009)



The Solution: Spectator Tagging

d(e,e'p$_s$)X

$$p_n = \left(M_D - E_S, -\vec{p}_S\right); \alpha_n = 2 - \alpha_S$$



$$p_S = \left(E_S, \vec{p}_S\right); \qquad \alpha_S = \frac{E_S - \vec{p}_S \cdot \hat{q}}{M_D / 2}$$

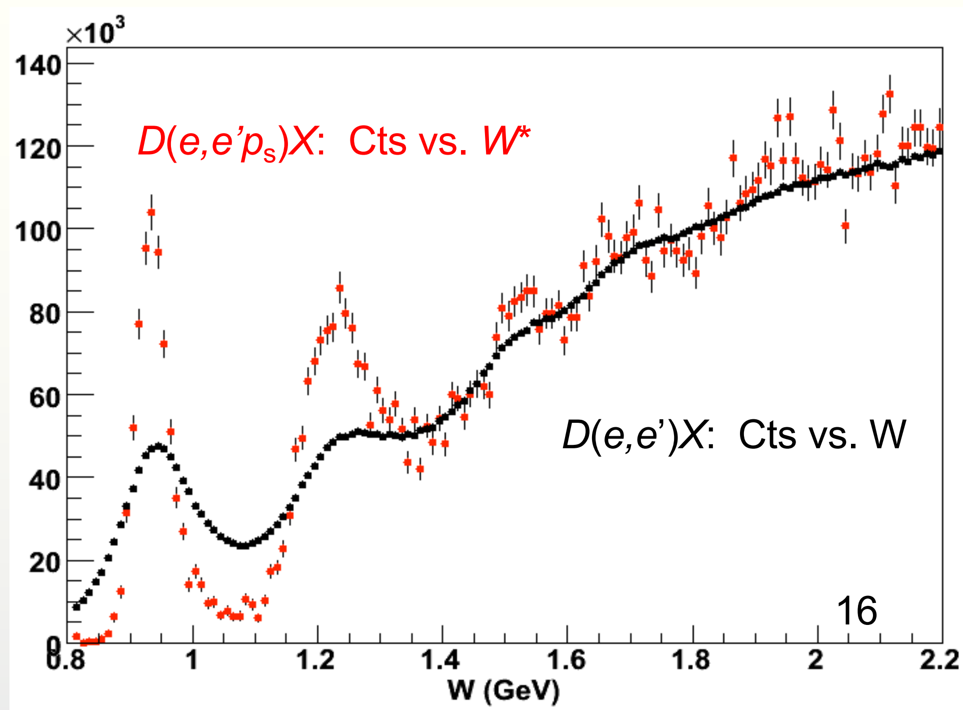
Relativistic Invariants

$$x = \frac{Q^2}{2 p_n^{\mu} q_{\mu}} \approx \frac{Q^2}{2M\nu(2-\alpha_S)}$$

$$Q^2$$

$$M^{*2} = p_n^{\mu} p_{n\mu} \approx \left(M_n - \varepsilon - \frac{\vec{p}_S^{\,2}}{M_n}\right)^2 \approx M_n^2 - 2M_n\varepsilon - 2\vec{p}_S^{\,2}$$

$$W^{*2} = \left(p_n + q\right)^2 = M^{*2} + 2\left((M_D - E_s)\nu - \vec{p}_n \cdot \vec{q}\right) - Q^2$$
$$\approx M^{*2} + 2M\nu(2-\alpha_s) - Q^2$$

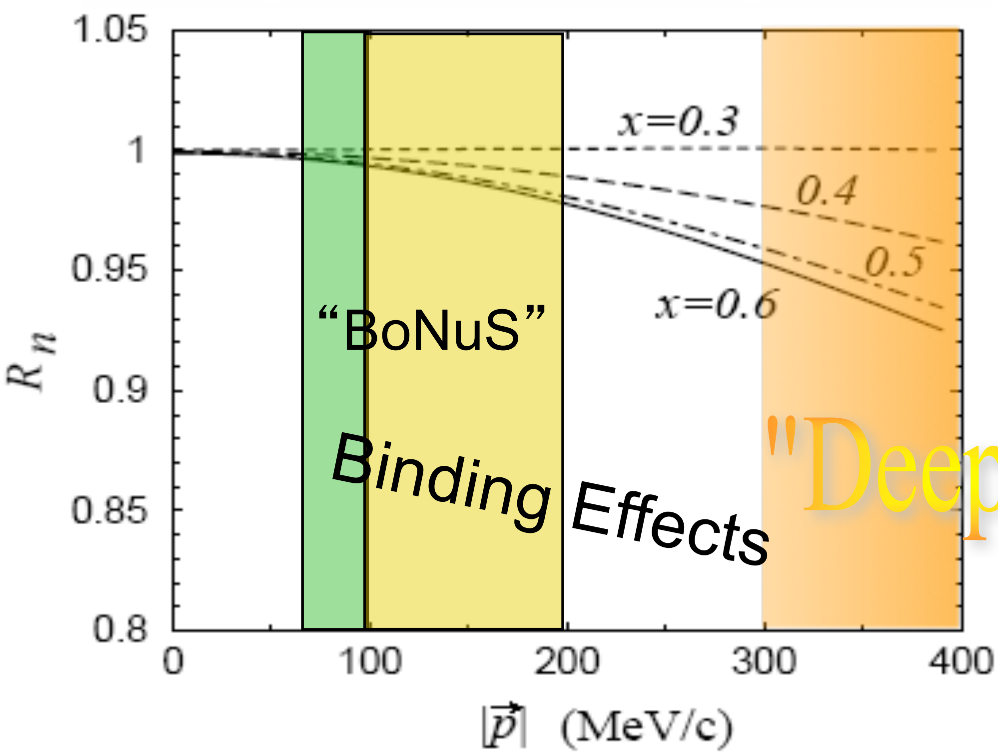


W. Melnitchouk, A.W. Schreiber and A.W. Thomas,

Phys. Lett. B335, 11 (1994); Phys. Rev. D 49, 1183 (1994).

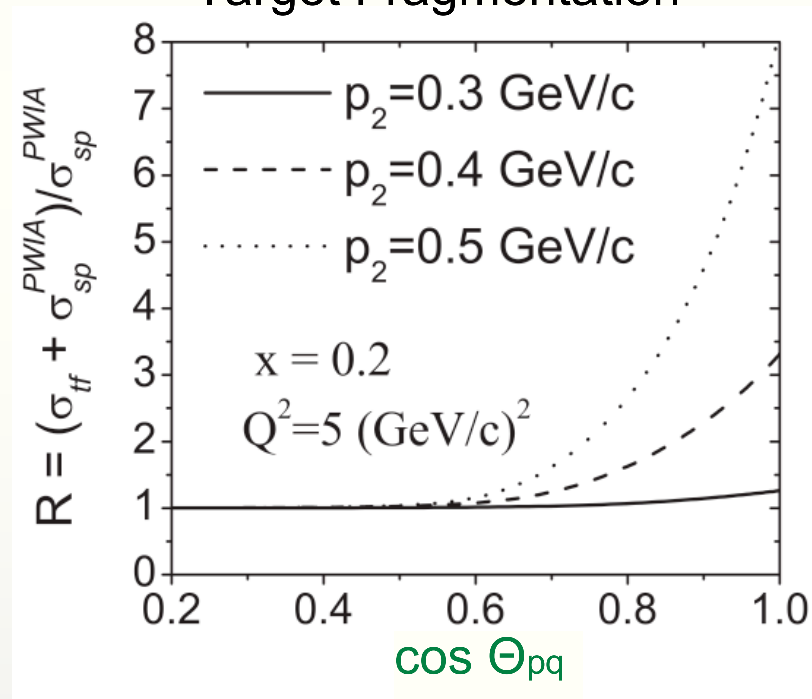
Modifications to Simple Spectator Picture

$$R_n \equiv F_2^{n(eff)}(W^2,Q^2,p^2)/F_2^n(W^2,Q^2)$$



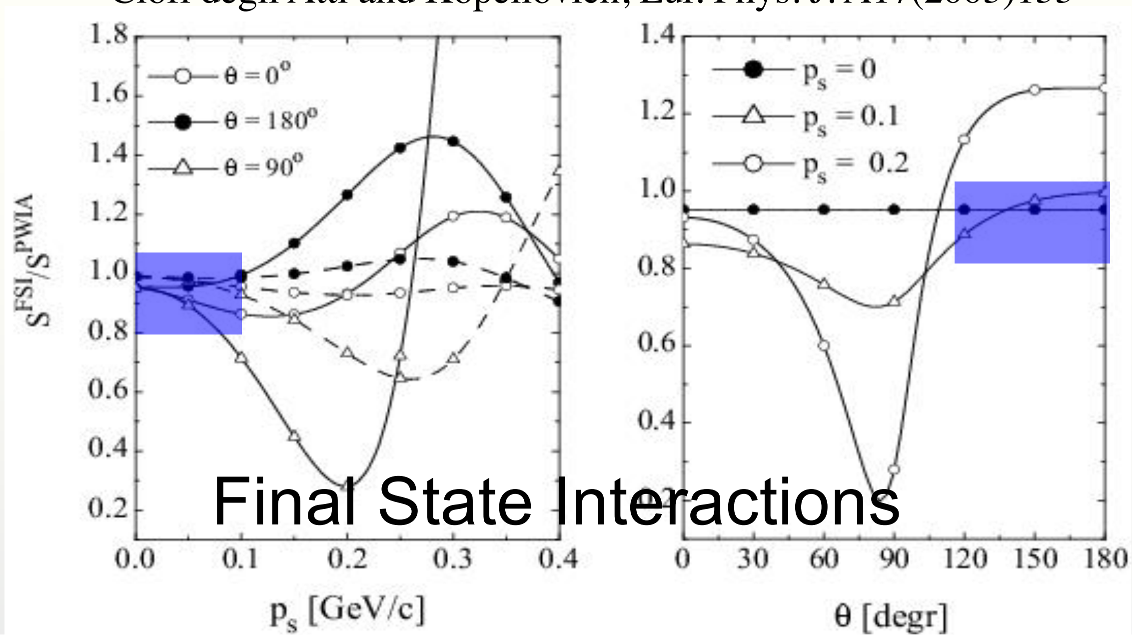
"Deeps"...

Target Fragmentation



Palli et al, PRC80(09)054610

Ciofi degli Atti and Kopeliovich, Eur. Phys. J. A17(2003)133



Alternative: Pole extrapolation

$$t' = M^{*2} - M_n^2 = (P_D - p_s)^2 - M_n^2 = \left(M_D - \sqrt{M_p^2 + \vec{p}_s^{\,2}}\right)^2 - \vec{p}_s^{\,2} - M_n^2 \approx -2\left(M_n \varepsilon + \vec{p}_s^{\,2}\right);\ \varepsilon = 2.2\ \text{MeV}$$

Wim Cosyn (Gent U.) , Misak Sargsian (Florida Intl. U.)

Mar 2, 2016 - 6 pages

EPJ Web Conf. 112 (2016) 03001
(2016-03-21)
DOI: 10.1051/epjconf/201611203001
Conference: C15-09-07.1
Proceedings
e-Print: arXiv:1603.00685 [nucl-th] | PDF

- Measure F_{2n} at fixed spectator angle, but varying momentum
- Extrapolate to on-shell neutron

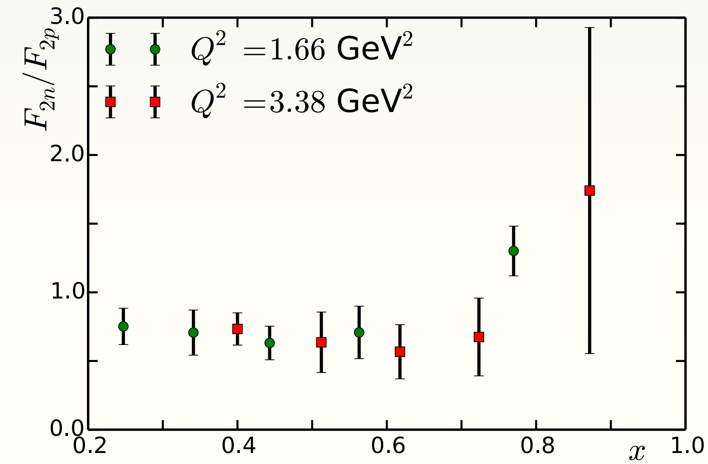


FIG. 4: (Color online) F_{2n} to F_{2p} ratio obtained using the pole extrapolation method on the renormalized BONUS data for $Q^2 = 1.66$ (green circles), 3.38 Gev^2 (red squares). The F_{2p} values are estimated using fit of Ref. [21].

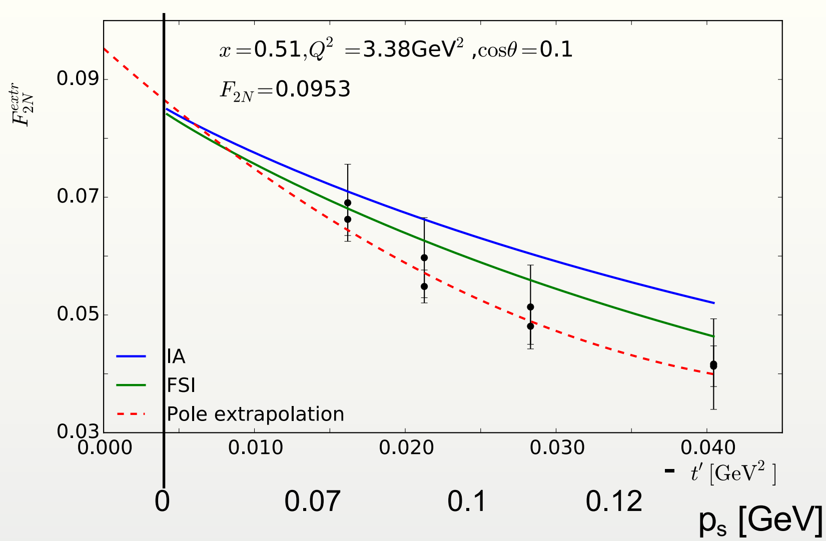
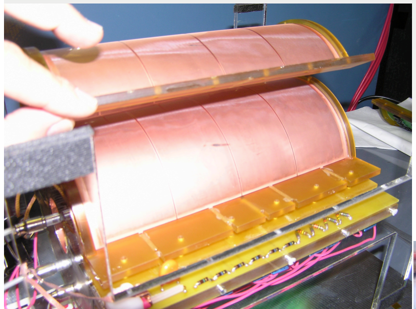
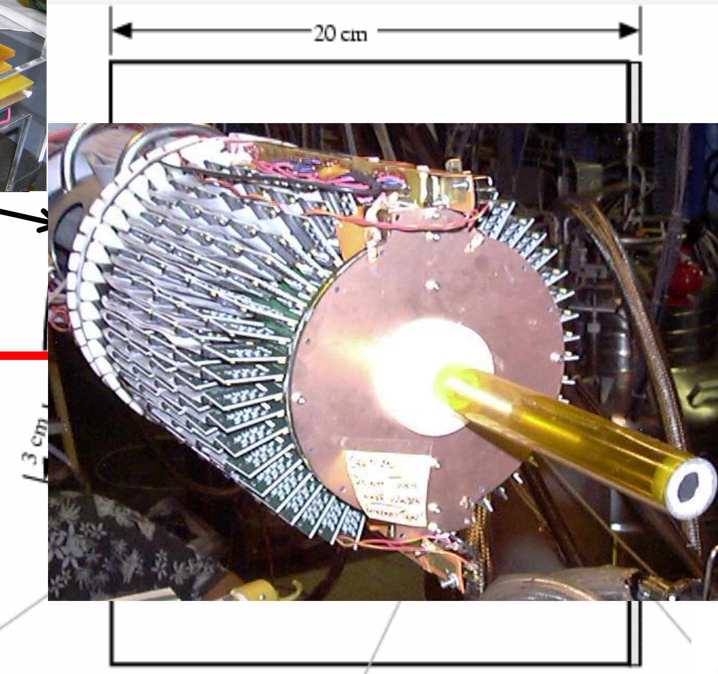


Figure 3. Example of the pole extrapolation method using the renormalized BONuS data (black circles) with the quadratic pole extrapolation curve (red dashed curve) as a function of $t'^2 = p_i^2 - m_n^2$. The IA (full blue curve) and FSI (full green curve) calculations are shown for comparison.

BoNuS RTPC



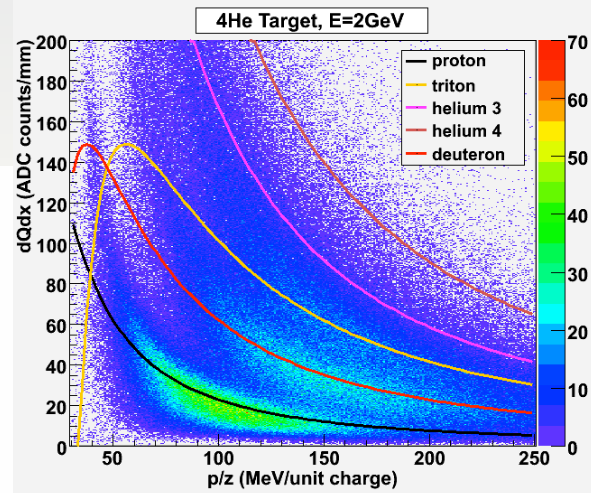
Gas
Electron
Multiplier



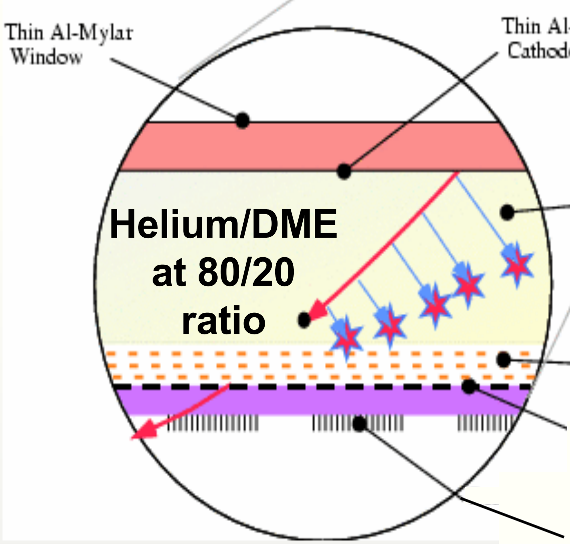
7 atm D_2 gas

Møller el.

e^- (to CLAS)



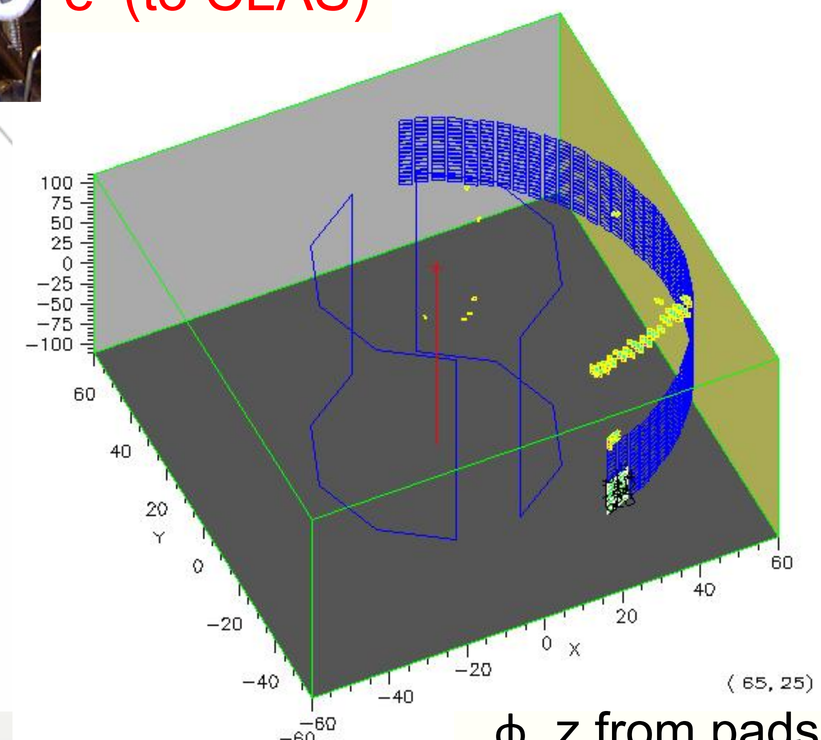
dE/dx from charge along track (particle ID)



Drift Region

3 GEMs

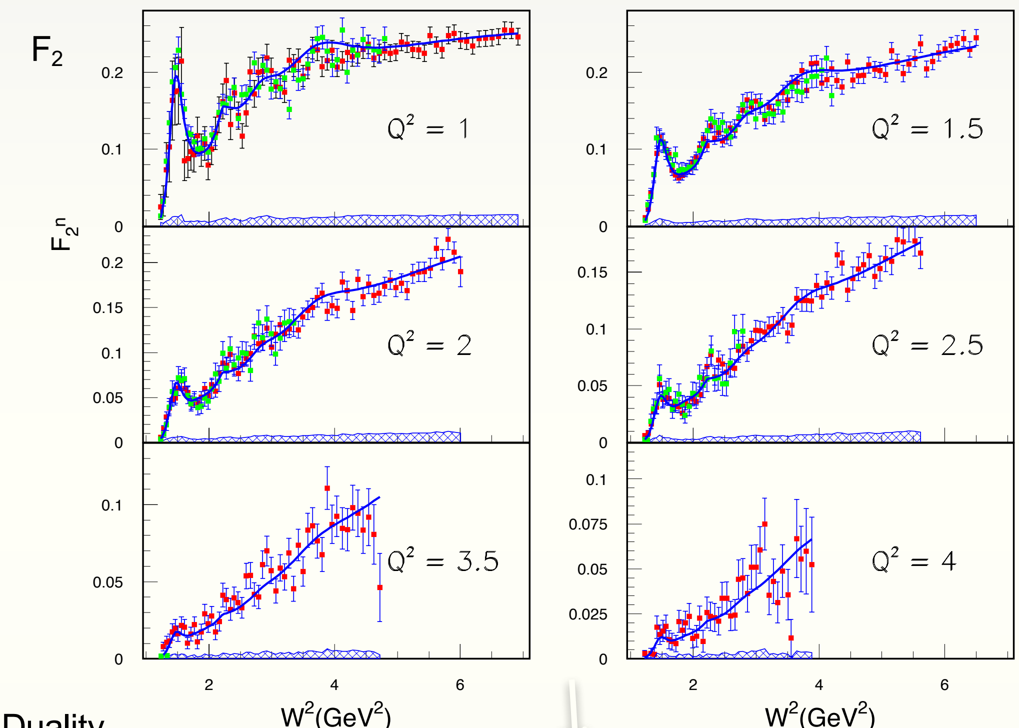
Readout pads and electronics

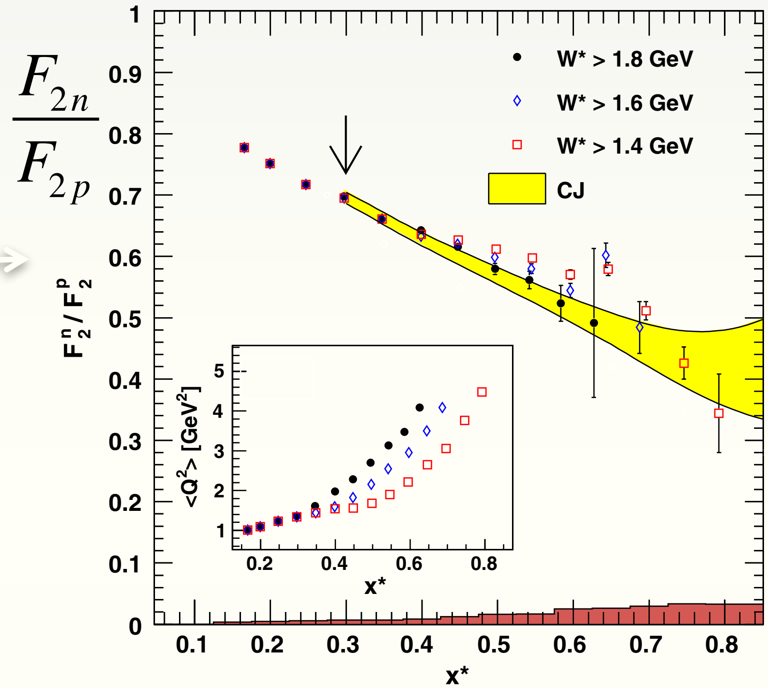


ϕ, z from pads
r from time

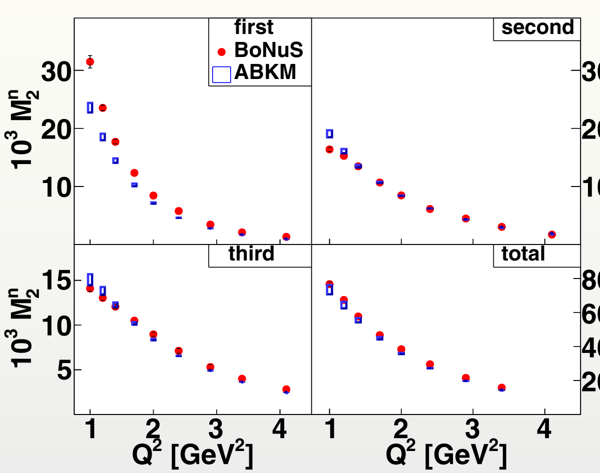
Nucl. Instr. Meth. **A592**, 273 (2008)

Spectator Tagging – BONuS6 Results

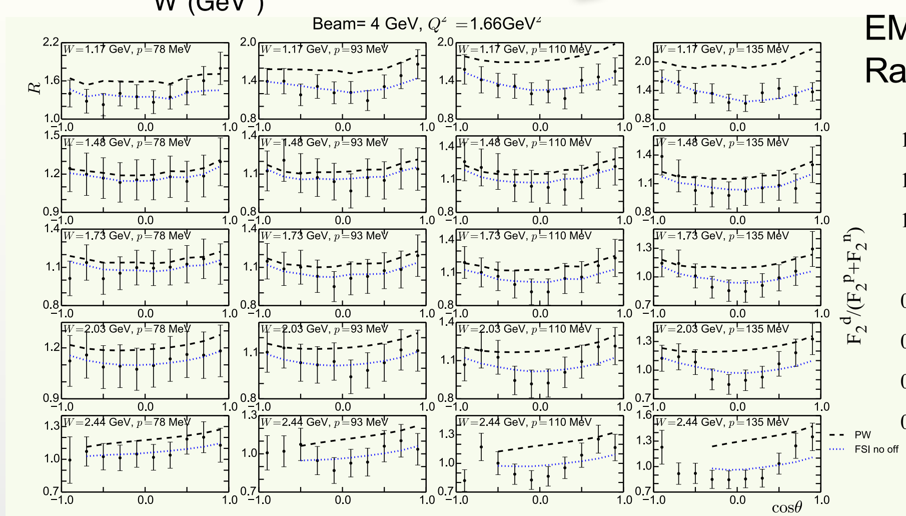




Duality

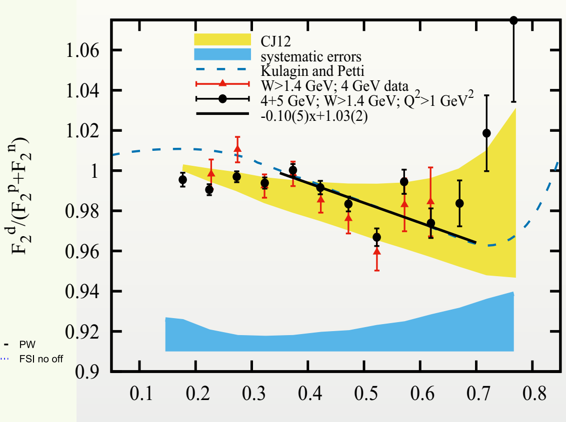


FSI: Cosyn et al.



EMC Ratio

PHYSICAL REVIEW C **92**, 015211 (2015)

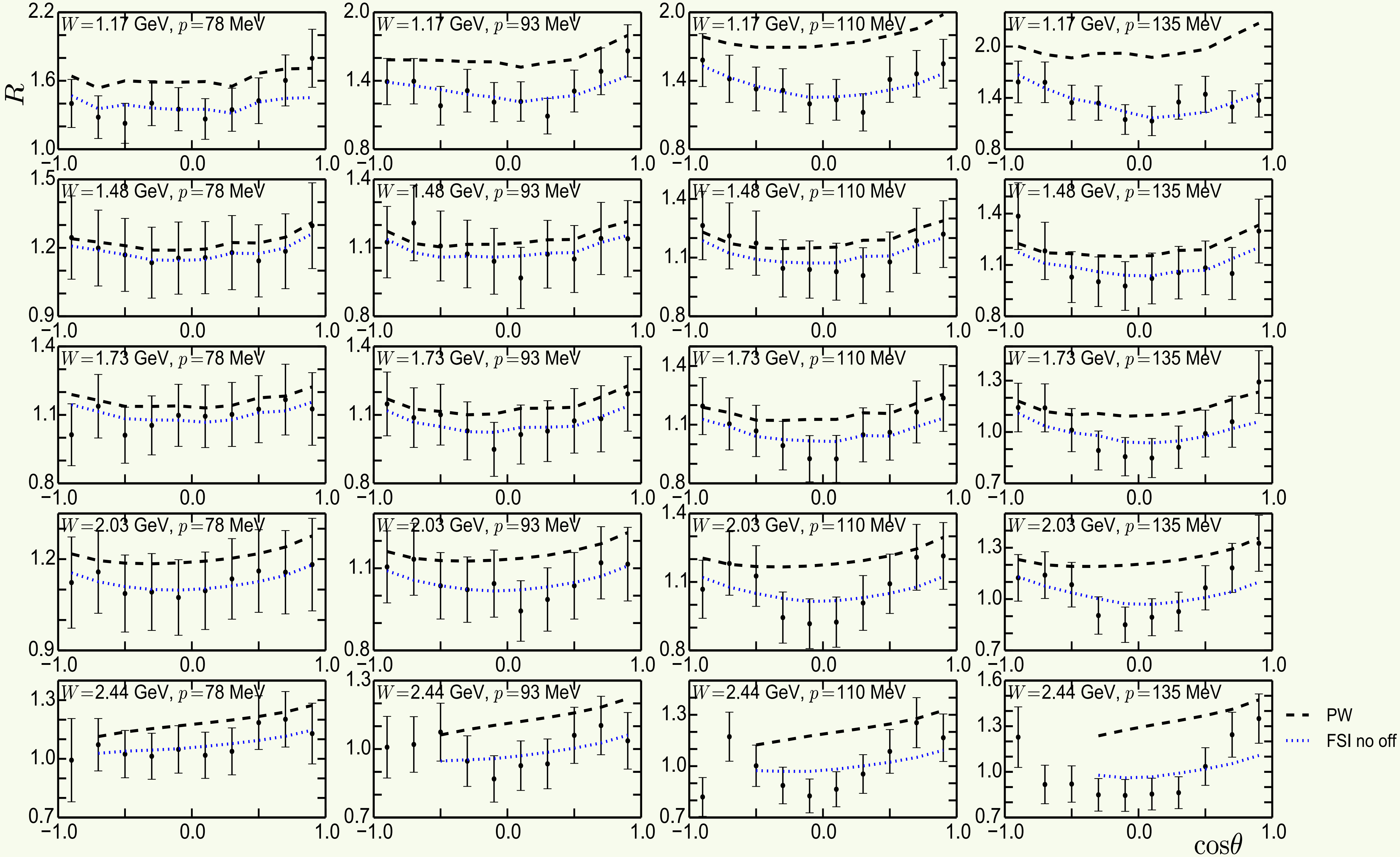


FSI - BONuS Results

FSI: Cosyn et al.

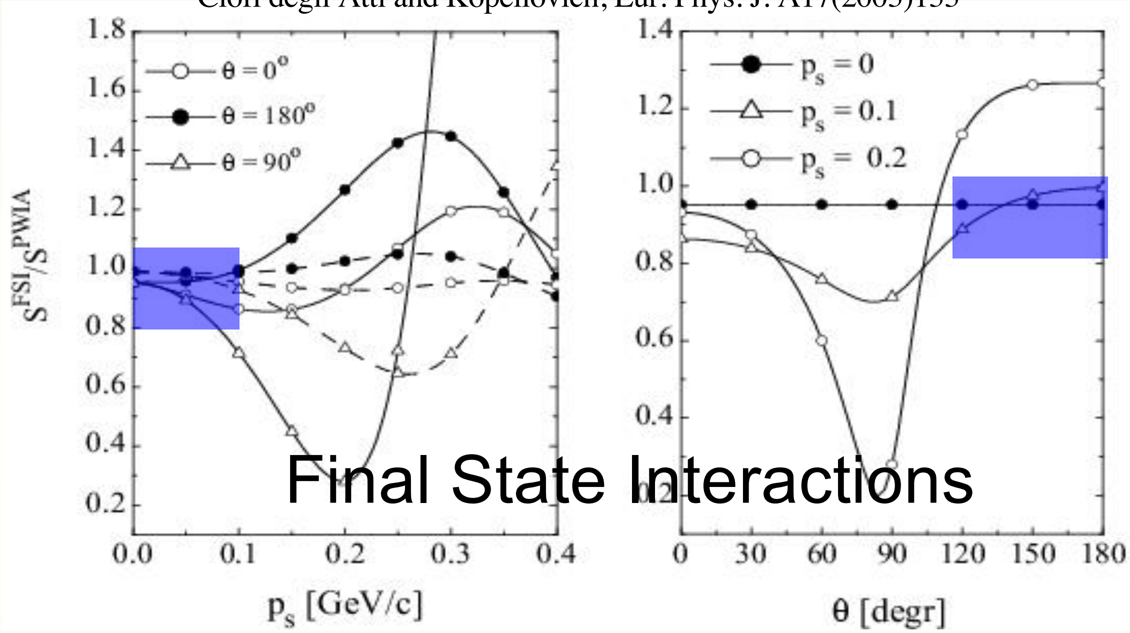
R = ratio of tagged SF in d(e,e'p_s) to “free” n SF, vs. momentum and angle (relative to **q** vector) of spectator p_s

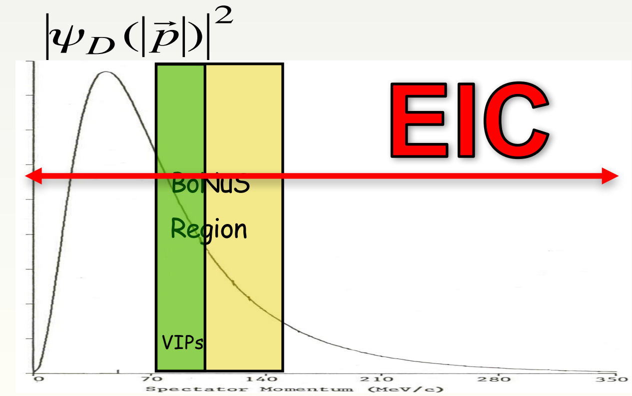
Beam= 4 GeV, $Q^2 = 1.66 GeV^2$



Spectator Tagging – E6 Results

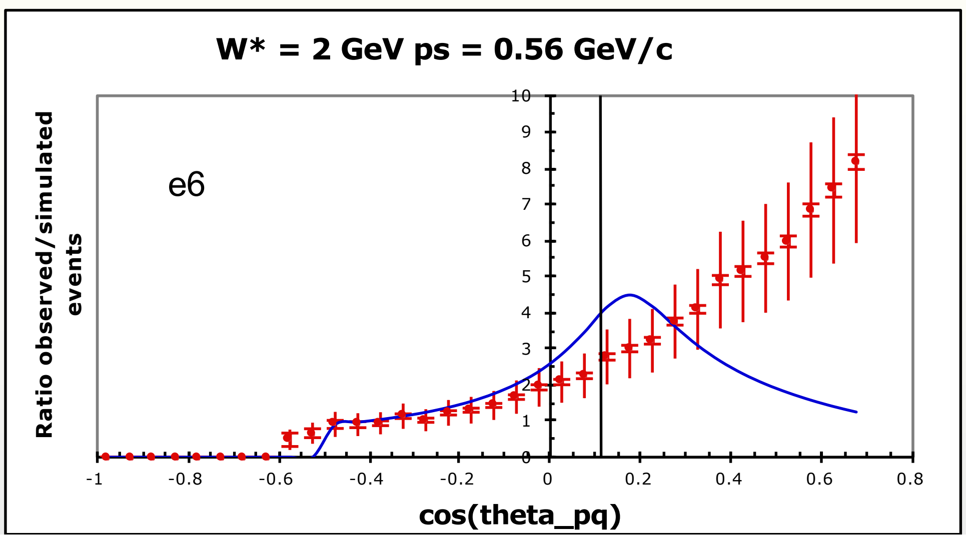
Ciofi degli Atti and Kopeliovich, Eur. Phys. J. A17(2003)133

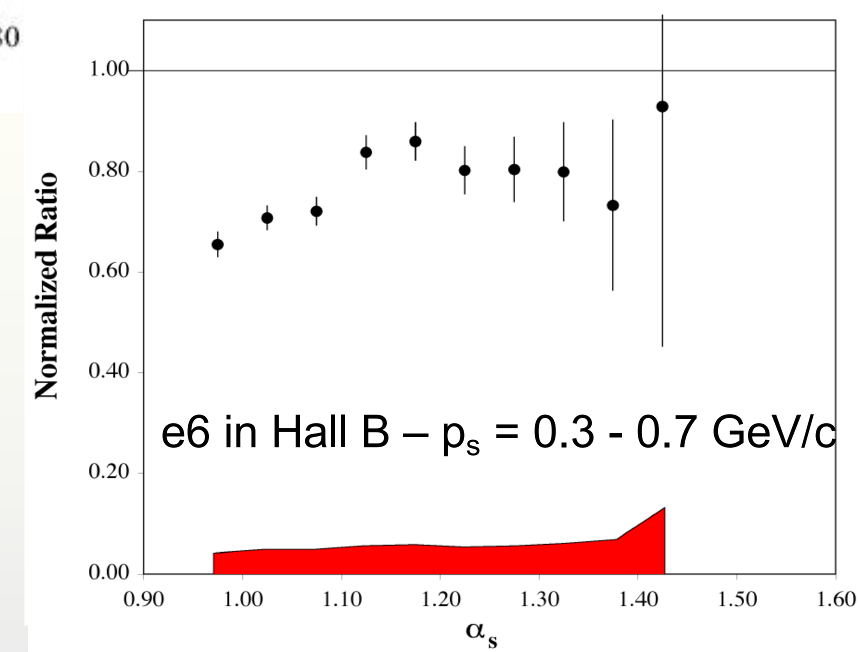




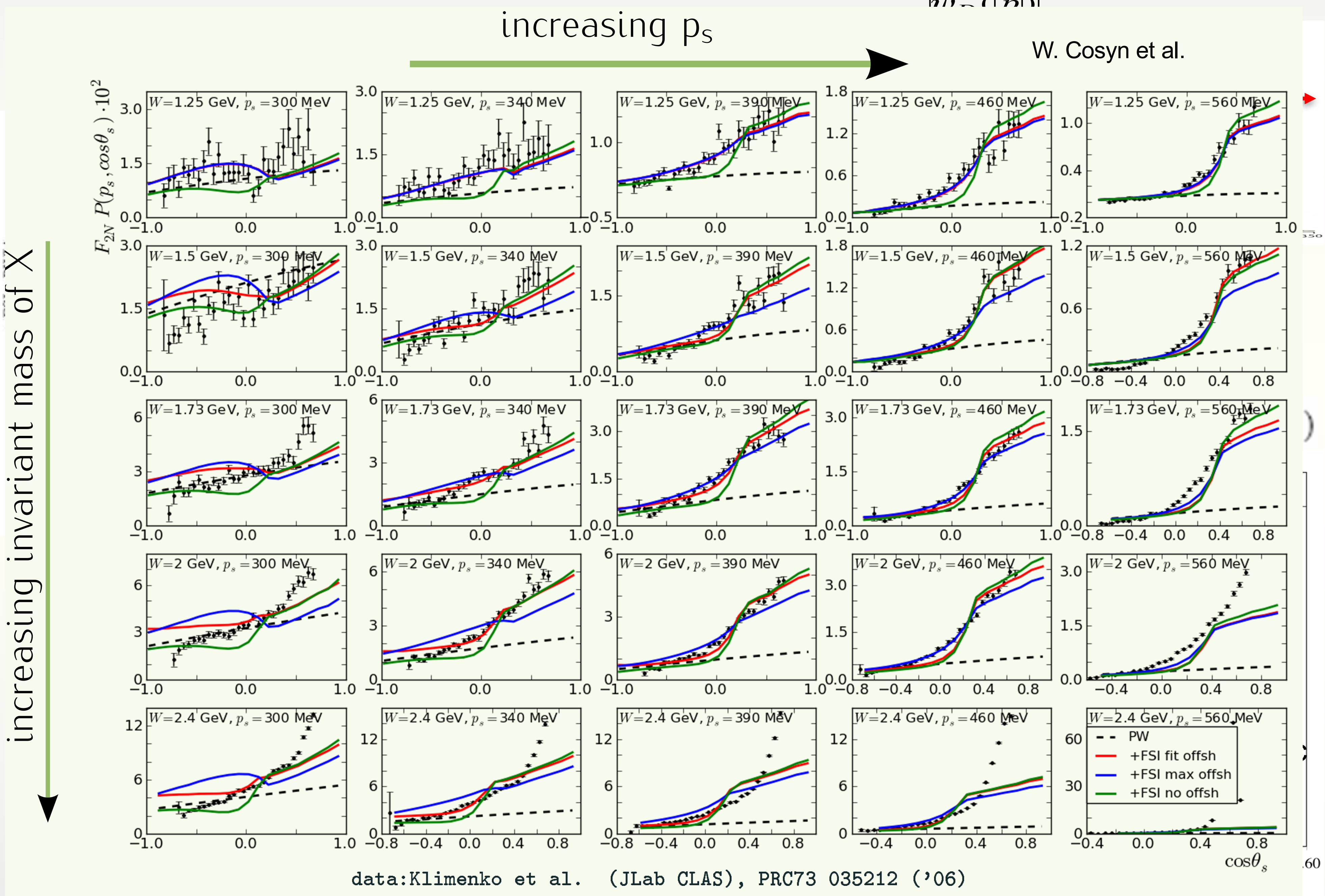
Finite coverage of WF

$$R_n \equiv F_2^{n(eff)}(W^2, Q^2, p^2)/F_2^n(W^2, Q^2)$$



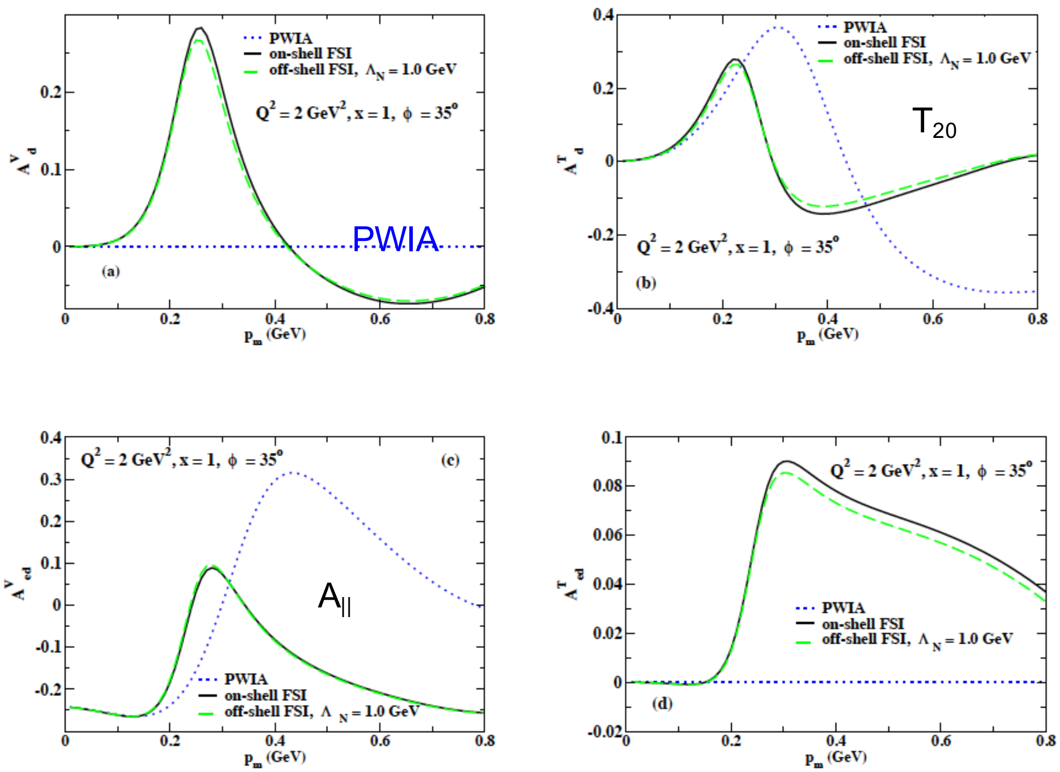


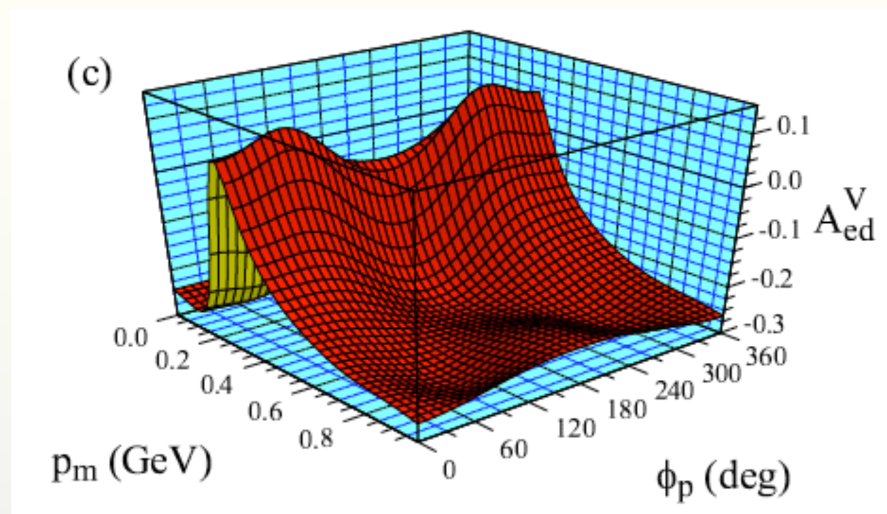
Spectator Tagging – E6 Results



Testing FSI Models in the quasi-elastic channel

- W. Van Orden and S. Jeschonnek have developed a fully relativistic description of cross sections, vector and tensor asymmetries for D(e,e’p)n, including (spin-dependent) FSI (based on known phase shifts)





Results from Jefferson Lab EG1b Experiment in CLAS

PHYSICAL REVIEW C **95**, 024005 (2017)

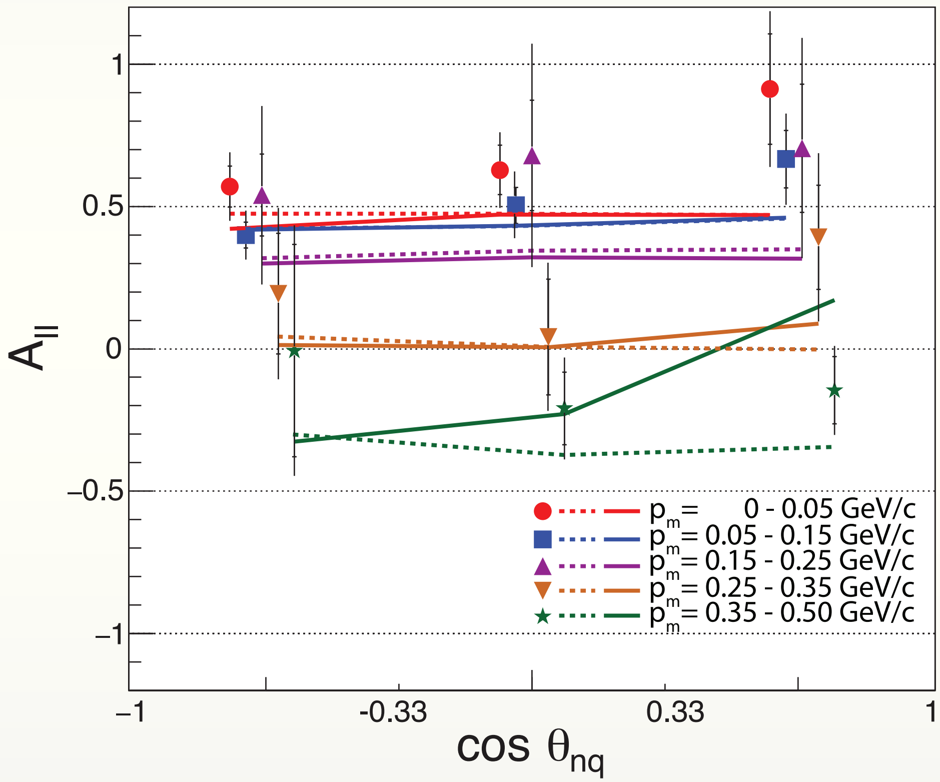


FIG. 11. $A_{||}$ for beam energies of 1.6 – 1.7 GeV and 0.38 $\text{GeV}^2/c^2 \le Q^2 \le 0.77\ \text{GeV}^2/c^2$,

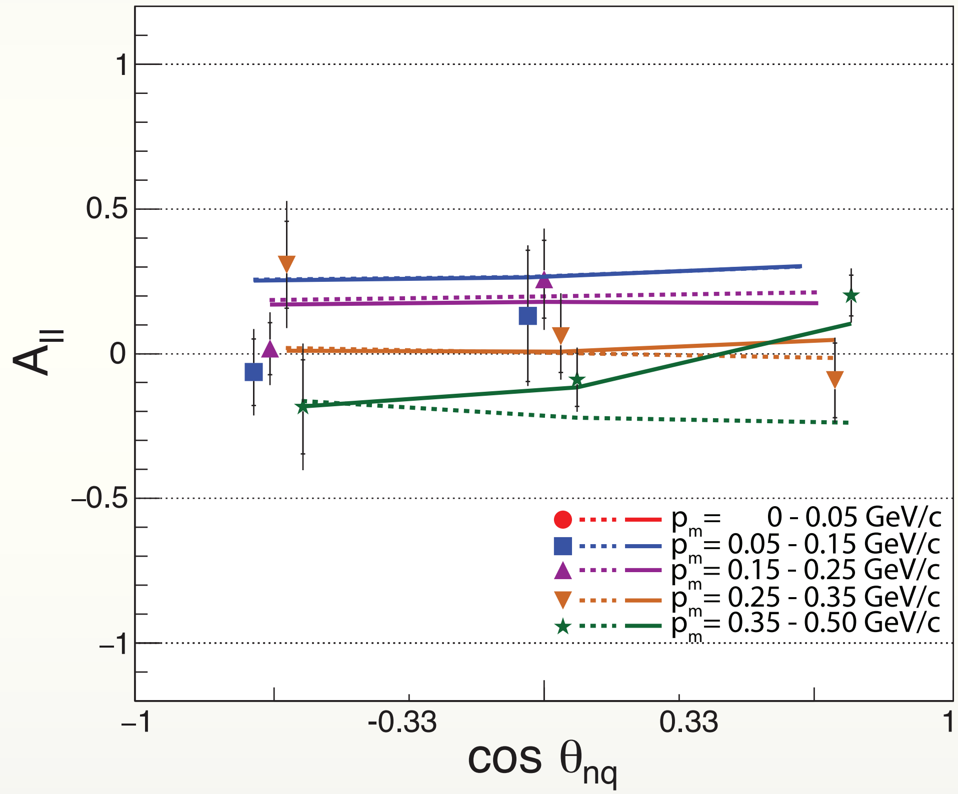
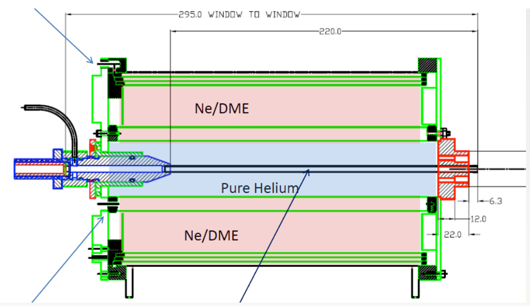
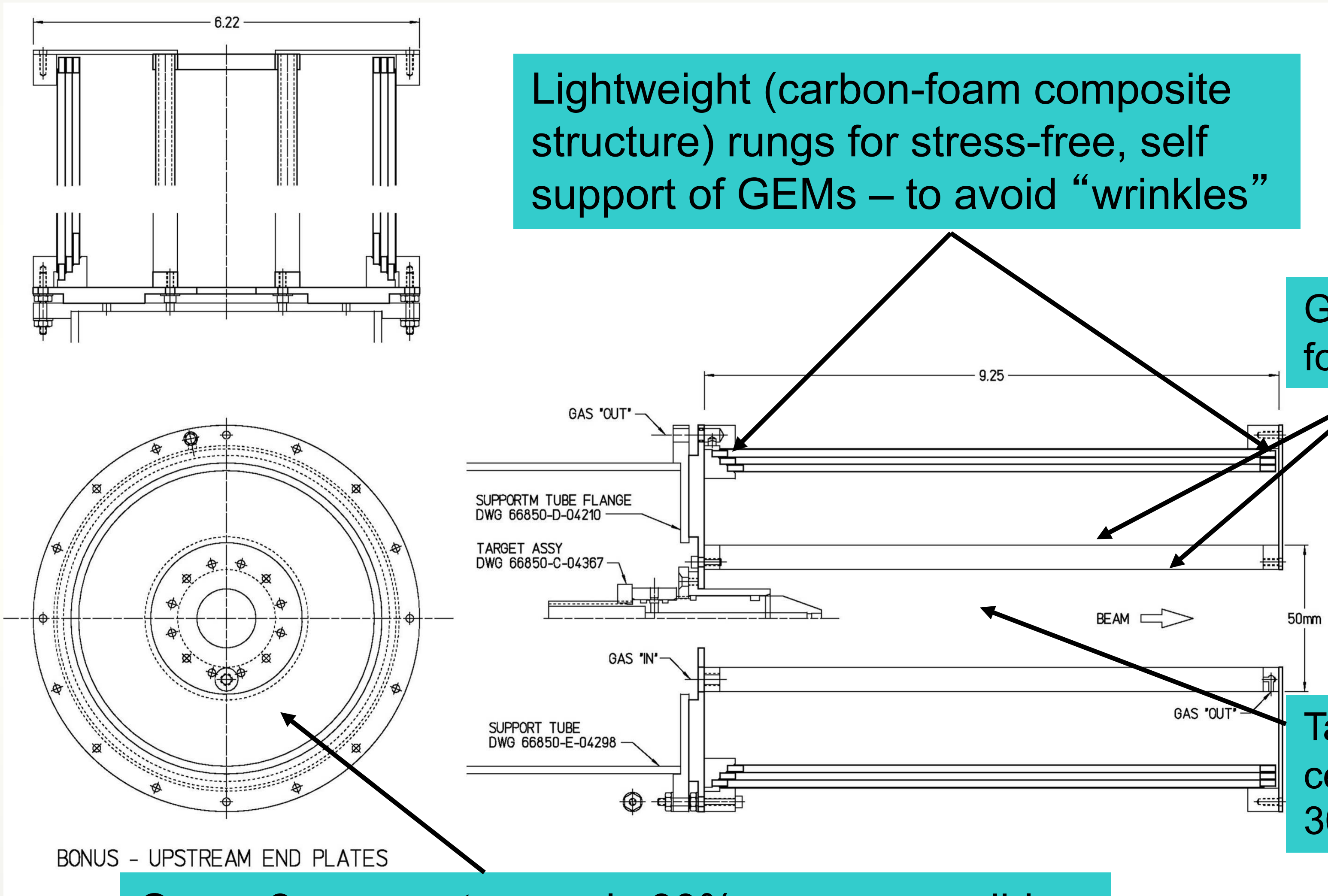


FIG. 12. $A_{||}$ for a beam energy of 2.5 GeV and the same Q^2

The total value for χ^2 , summed over all bins excluding the 5.x GeV data, is 165.6 for the PWIA model (dof=91, $p<3\times 10^{-6}$;
or χ^2=182.3 for dof = 103 when we include the 5.x GeV bins) and χ^2 = 121 (dof = 91, p ≈ 0.02) for the model with FSI included.



The 2nd RTPC (EG6)

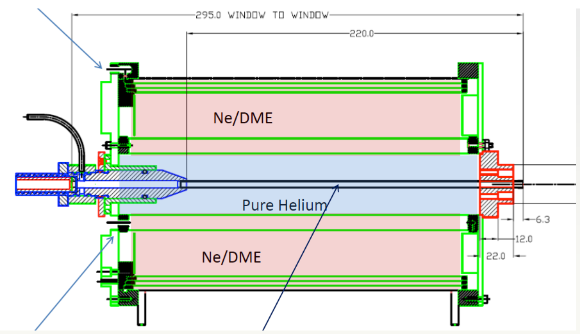


Lightweight (carbon-foam composite structure) rungs for stress-free, self support of GEMs – to avoid "wrinkles"

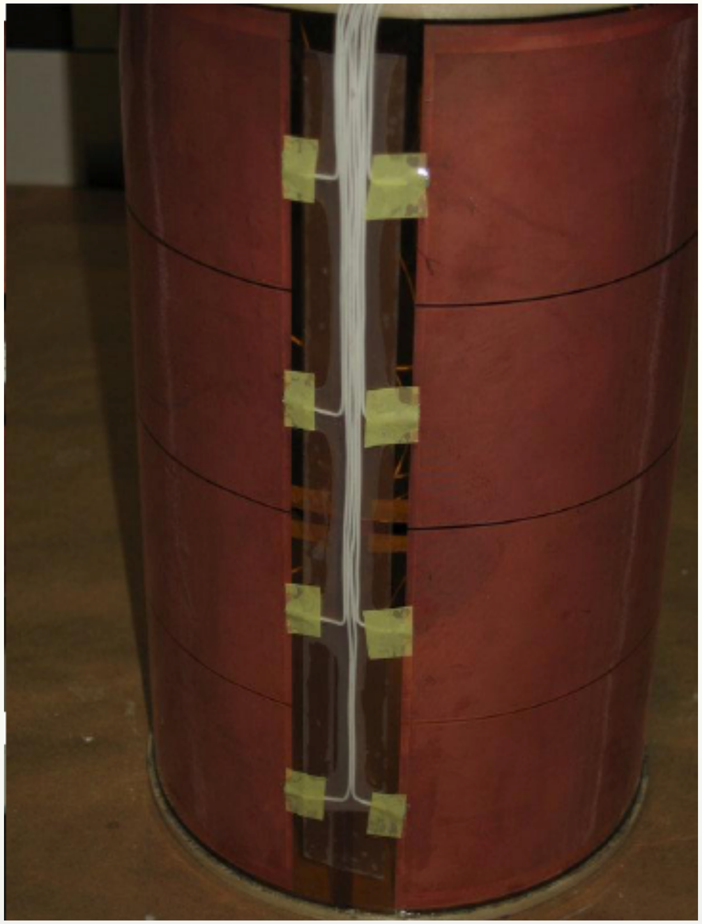
Ground and cathode foils, each 6μm thick

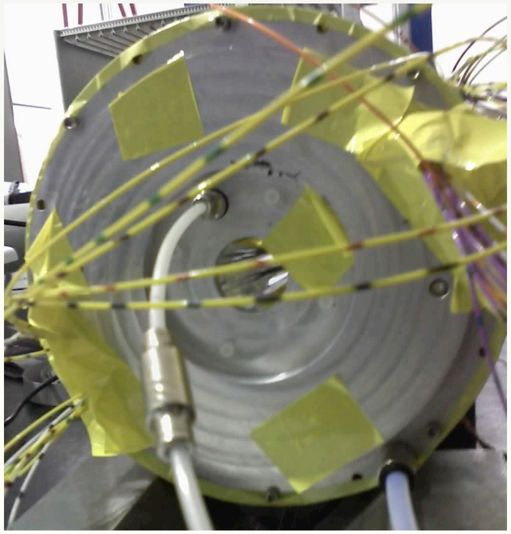
Target region - new cell – ID 4mm, 30μm thick wall

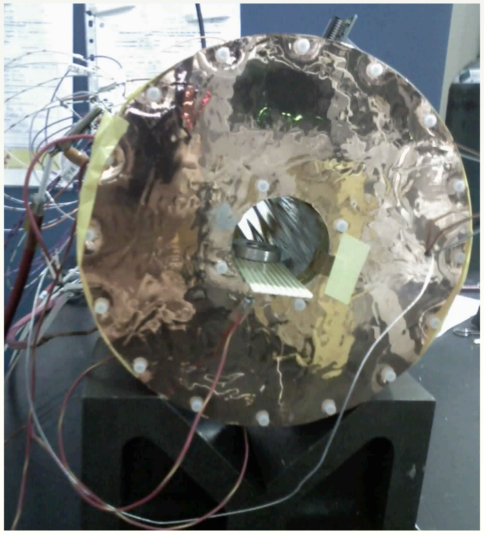
Open, 2π geometry – only 80% were accessible due to the GEM and readout pad sizes

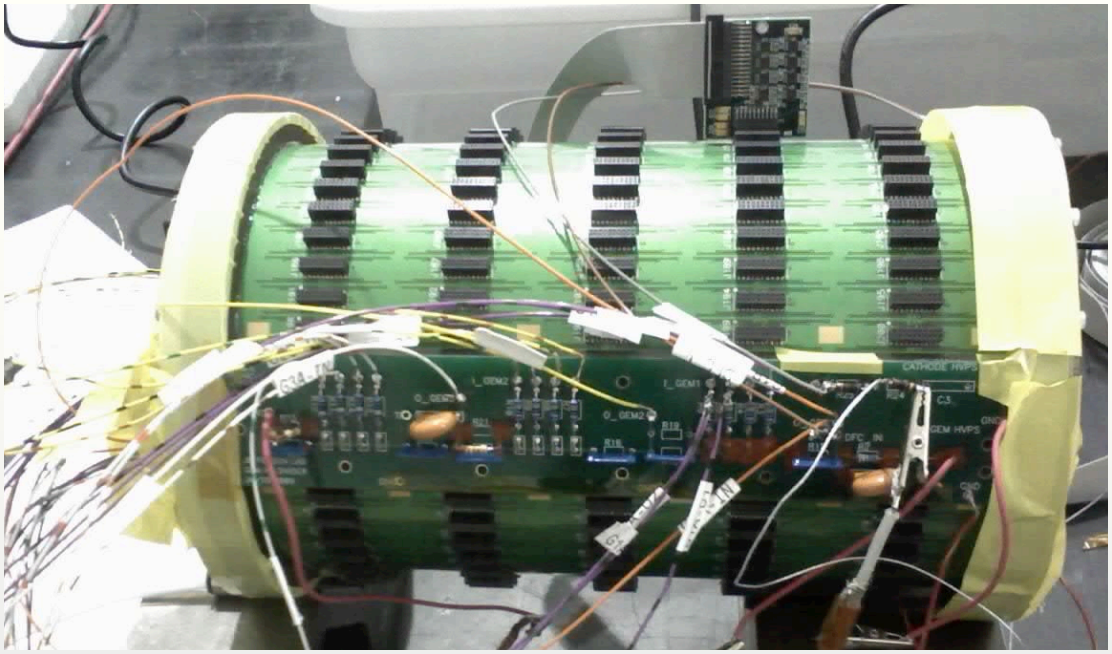


The 2nd RTPC (ii)



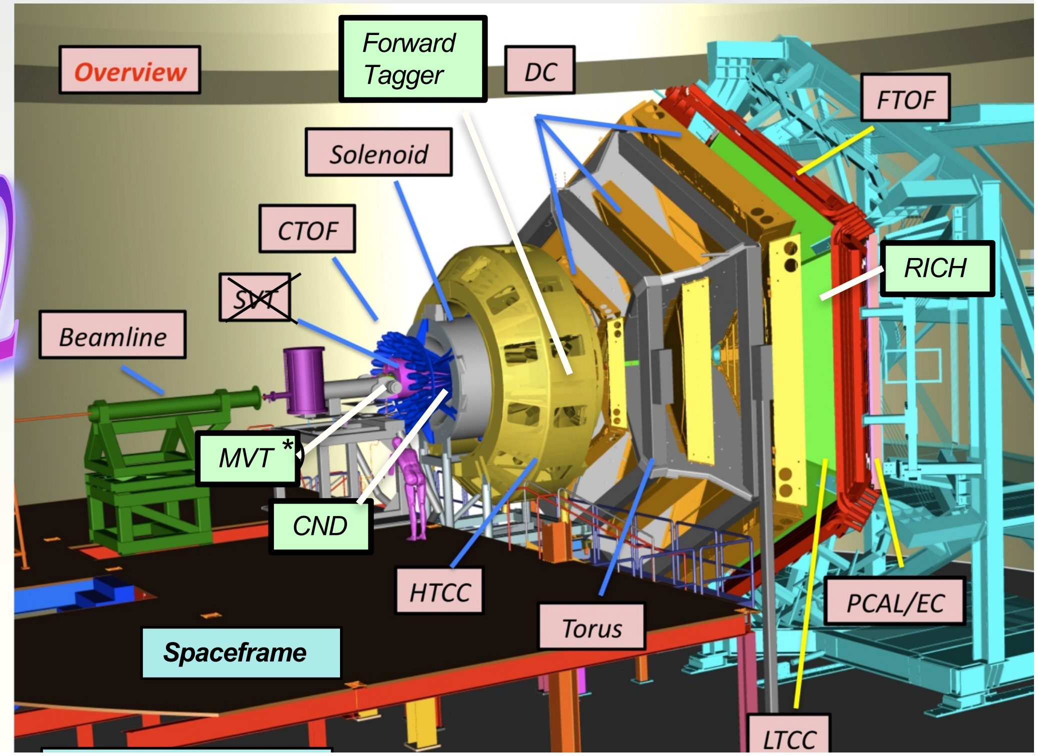






BONuS12 at 11 GeV

CLAS12

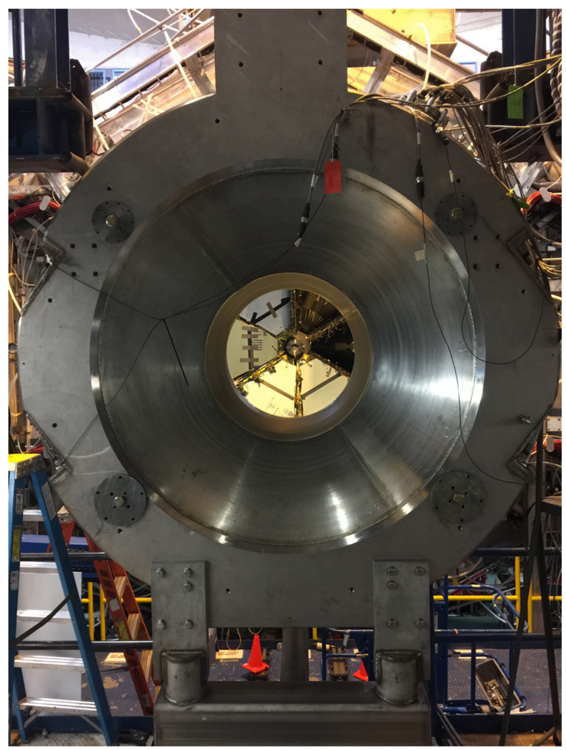


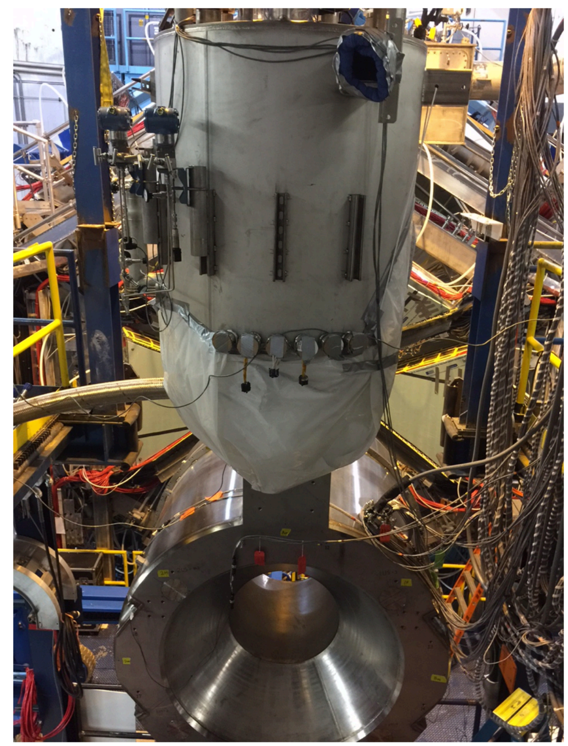
BoNuS12

E12-06-113

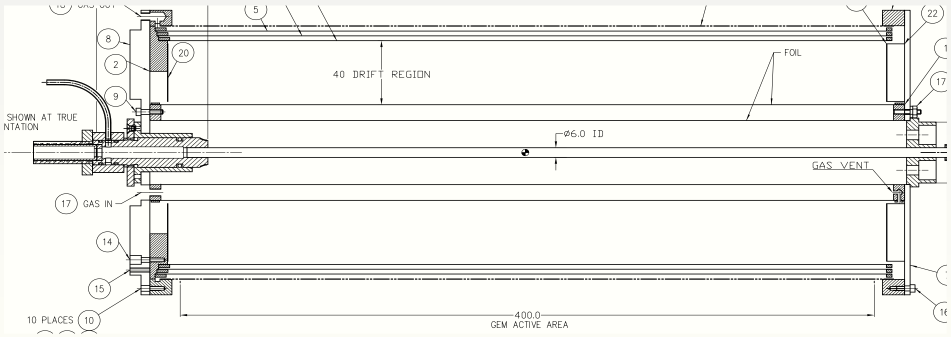
- Data taking for 35 days on D_2, 4 days on H_2 + 1 day aux. with $\mathcal{L} = 2 \cdot 10^{34}$ nuclei/cm^2 s^{-1}

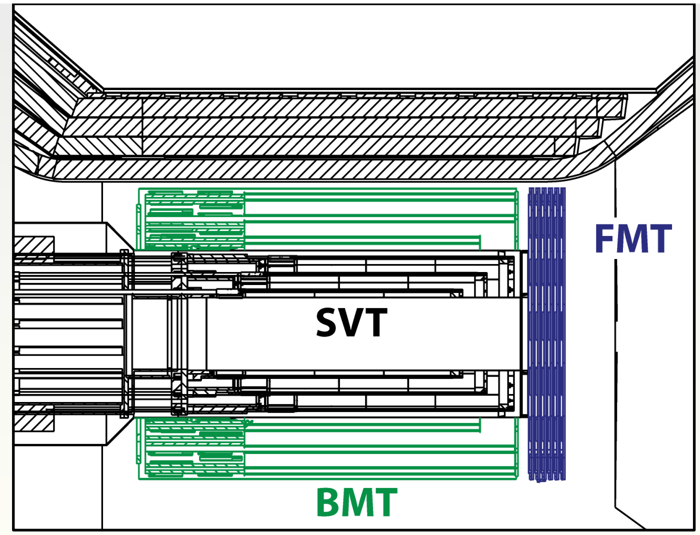
  plus 2 days commissioning at 2.2 GeV
- **NEW** RTPC detector, DAQ
- DIS region with
  - $Q^2 > 1$ GeV$^2/c^2$
  - $W^* > 2$ GeV
  - $p_s > 70$ MeV/c
  - $10° < \theta_{pq} < 170°$



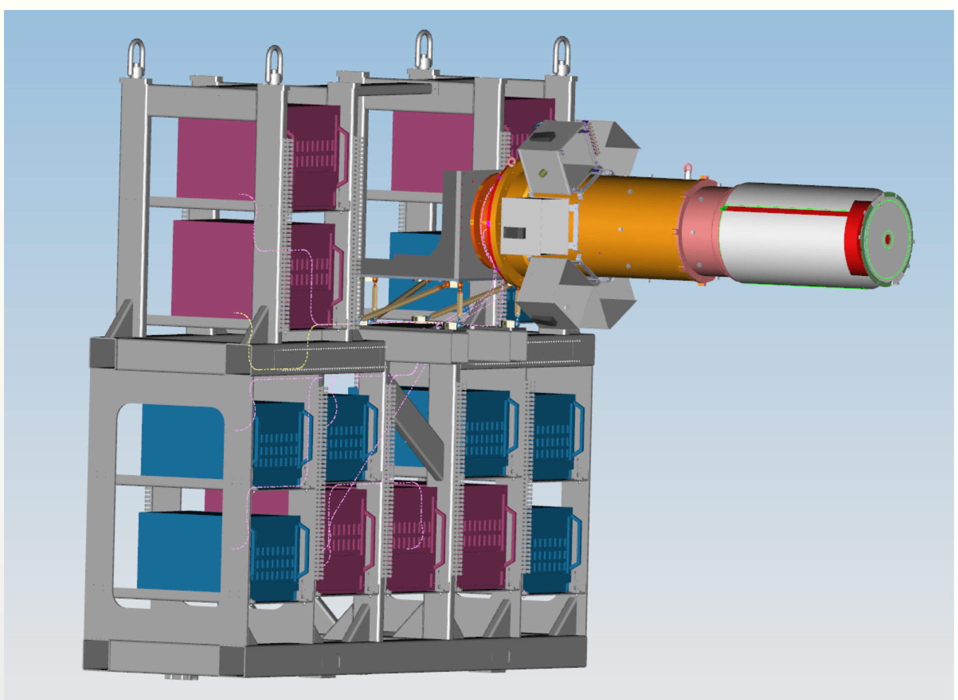


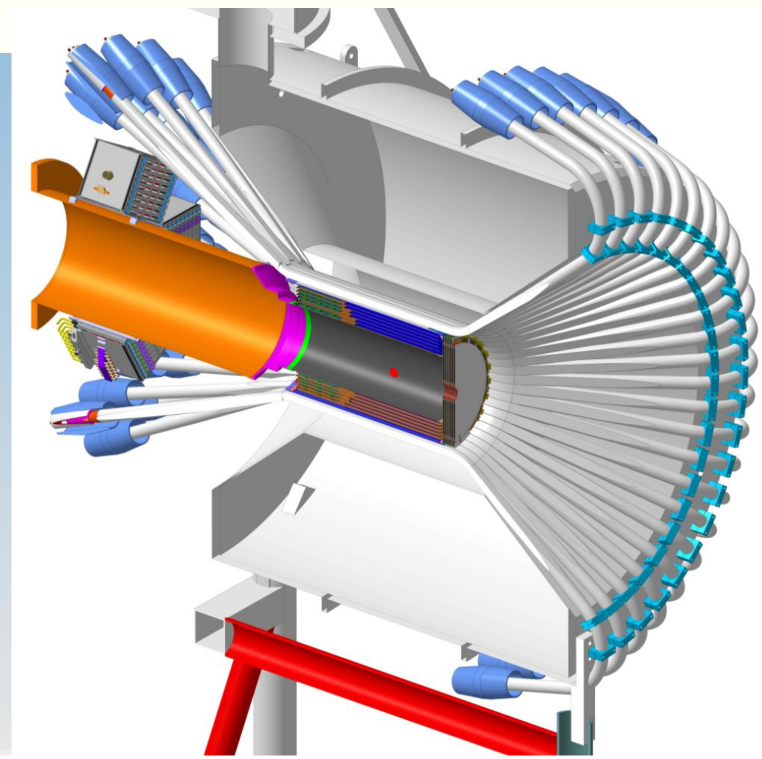
BONuS12 at 11 GeV





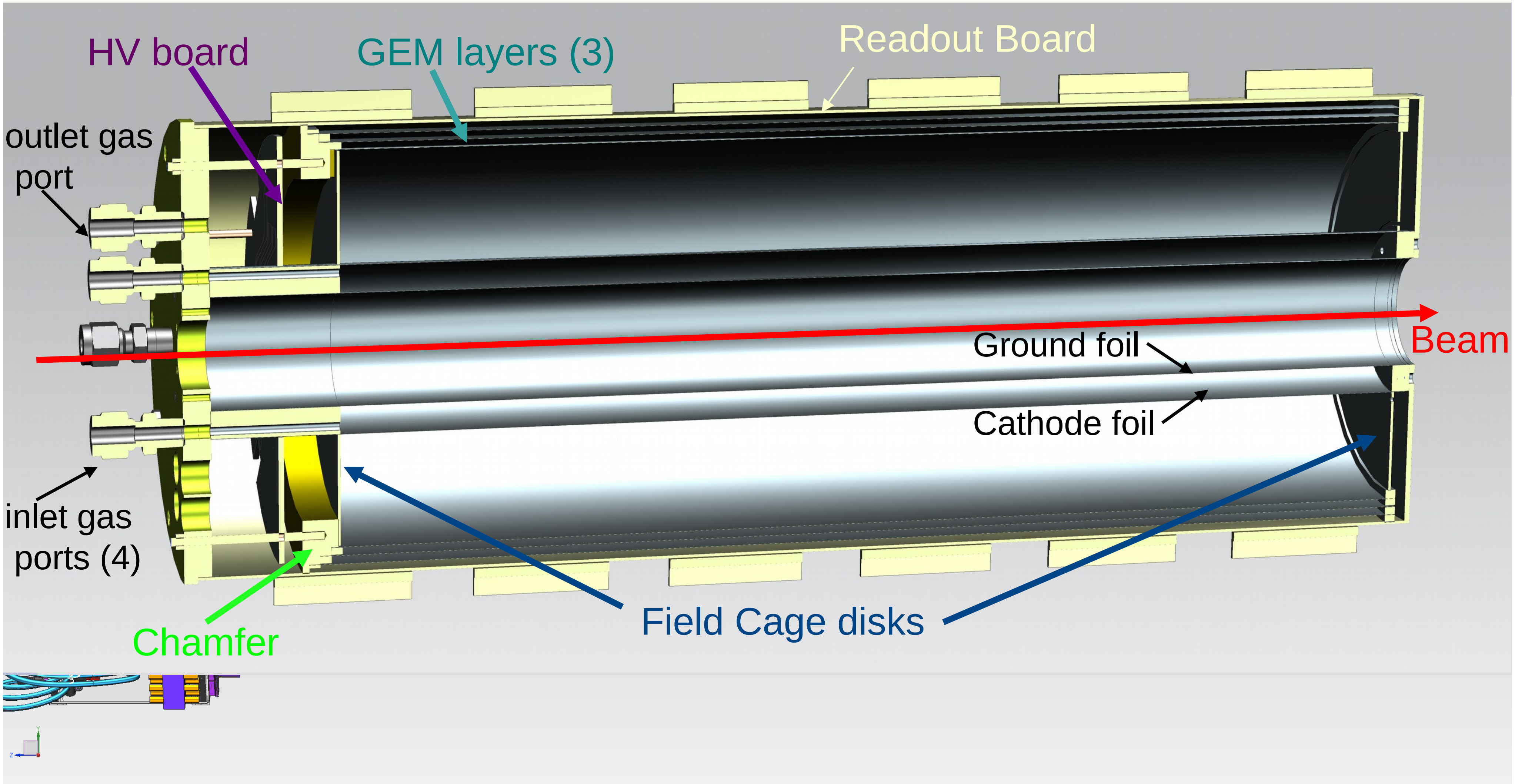
Central Detector





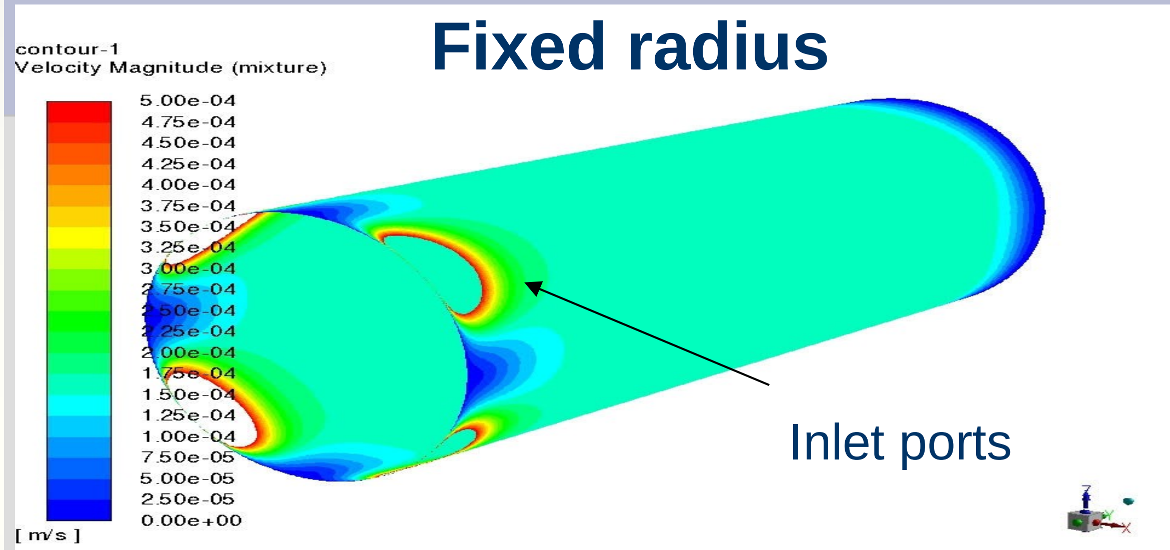
BONuS12 RTPC replaces SiVtxT + Barrel μmegas (but forward Vtx tracking needed!)

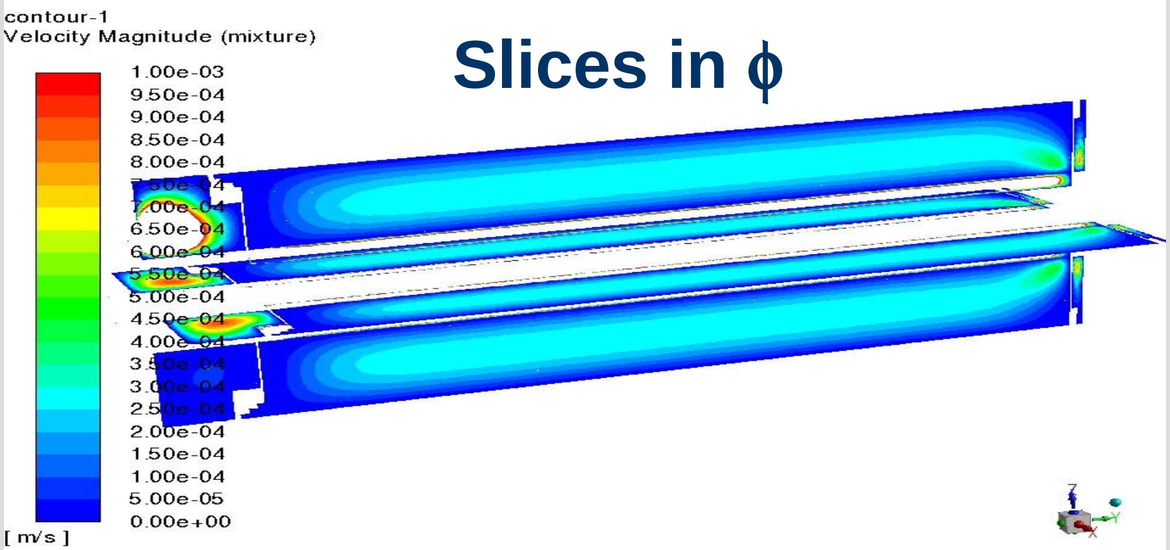
Completed RTPC w/ target



Velocity profiles from CFD

Silviu Covrig





Assumptions:

→ 0.2 L / min

→ Premixed

Conclusions:

→ Current design provides relatively uniform flow

Basic Assembly of GEMs

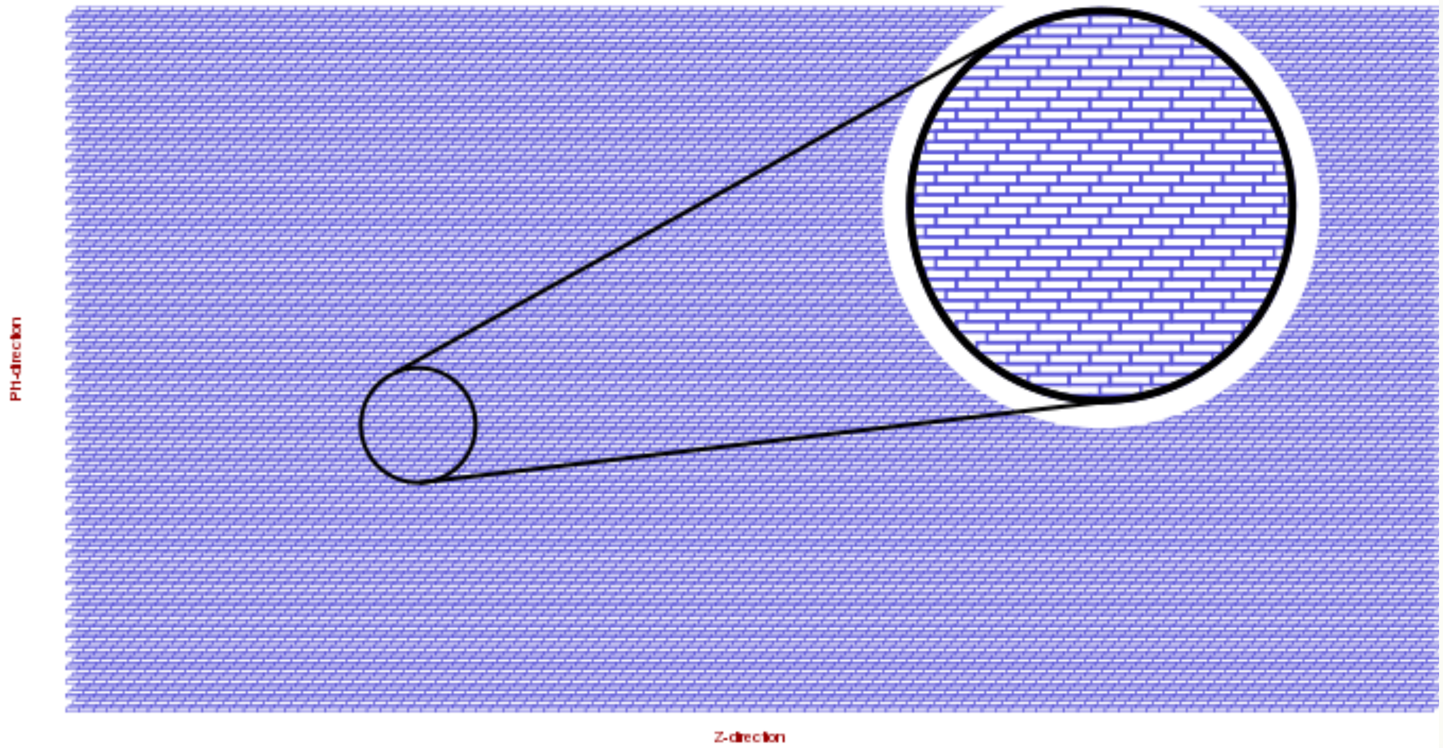
→ GEM layers will be constructed using similar process to KLOE2 / EG6

→ Each GEM layer is wrapped on a cylidrical mandrel

→ Epoxy inner (downstream) and outer (upstream) rings

RTPC read out board

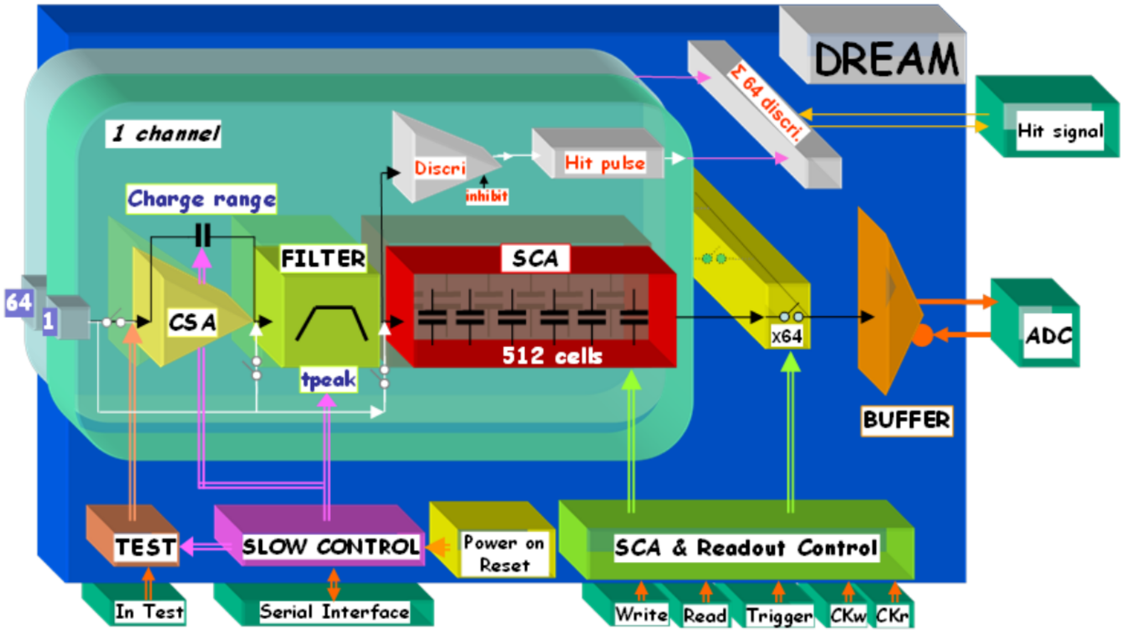
View of the readout board



180 rows, 96 columns for a total of 17280 pads
Each pad covers 4 mm in z and 2 degrees in phi
Rows shifted by ¼ pad size in z from one another
Read out by Micromegas DREAM electronics

DREAM electronics developed for the Micromegas of CLAS12

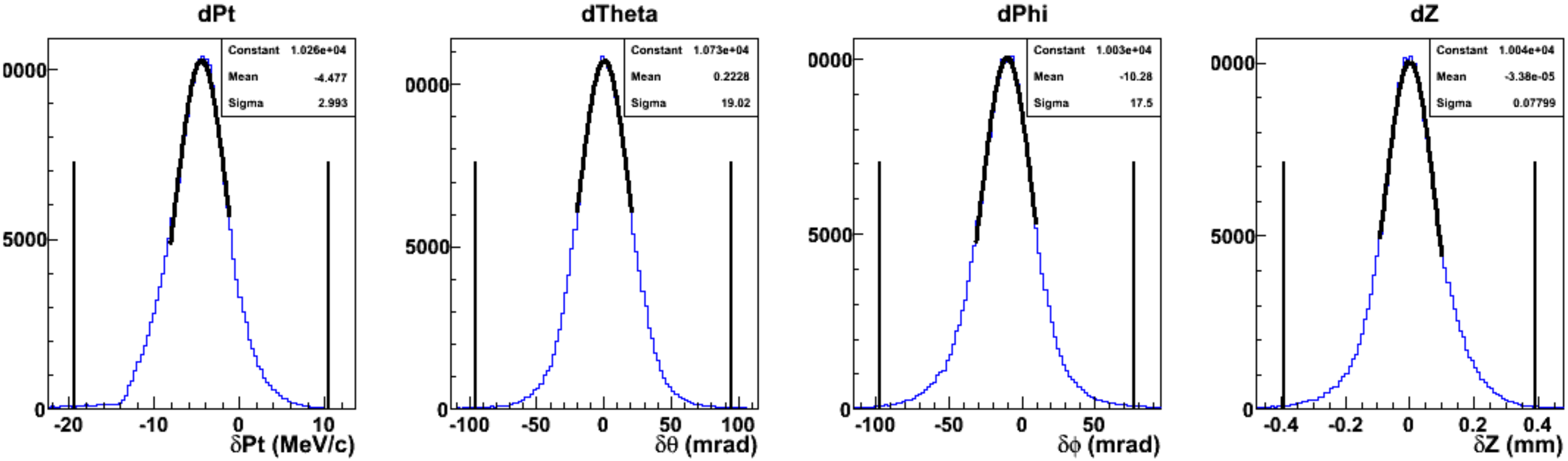
- 512 memory cells/channel
- read out selected cells after trigger
- Low noise
- Analogue multiplexed output
- Latency up to 16μs

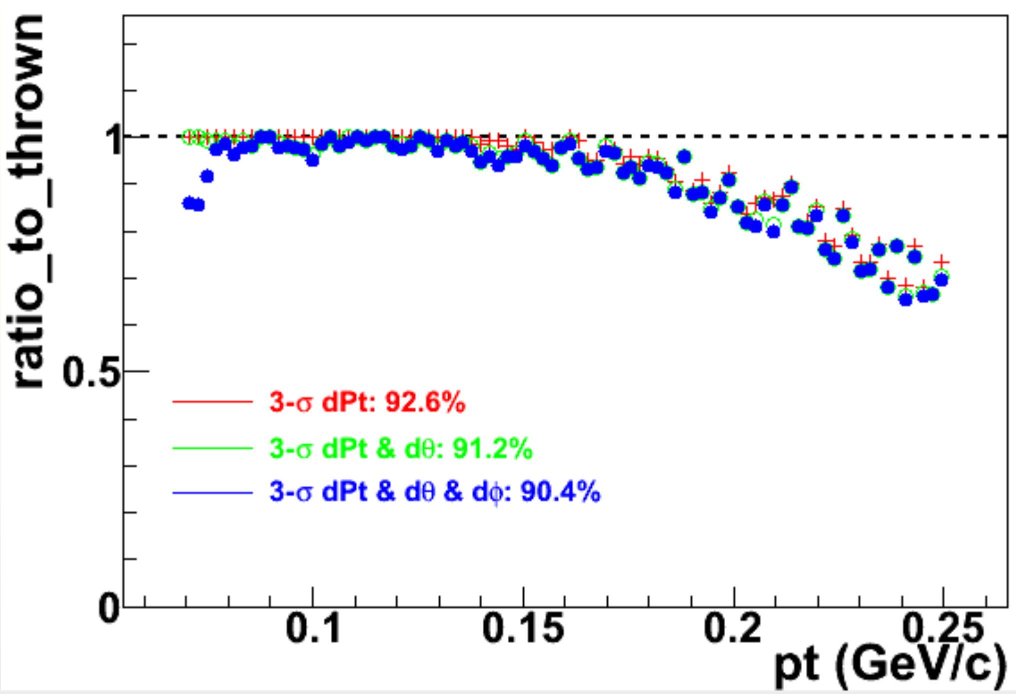


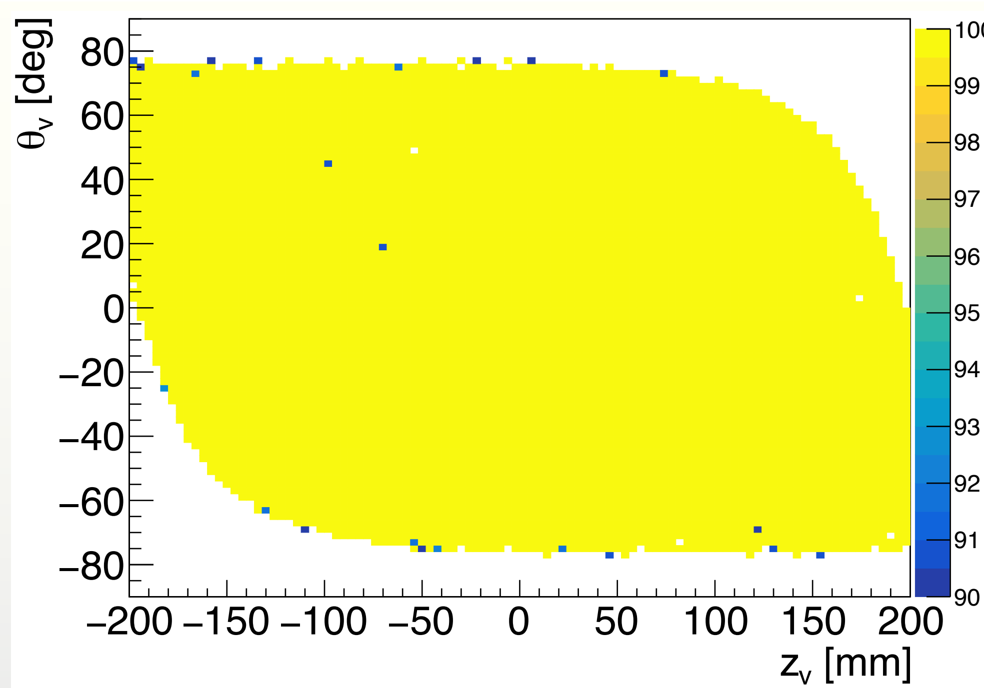
BONuS12 will use DREAM electronics

- Already available on site
- Fits BONuS12 needs
- Contract signed with Saclay (test bench + manpower)
- Need to update the firmware
- Test bench working at Old Dominion University
- BONuS12 will use available FEU and signal cables from barrel Micromegas
- Adaptation board to protect the electronics from over current

Simulation

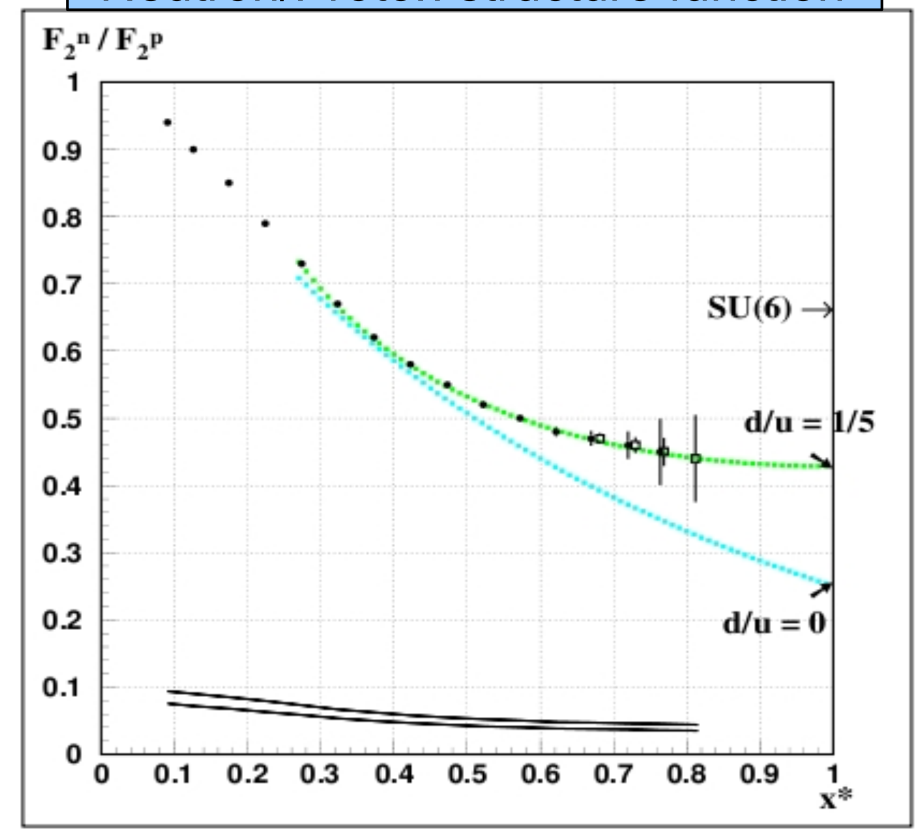

dPt
Constant 1.026e+04
Mean -4.477
Sigma 2.993
δPt (MeV/c)
dTheta
Constant 1.073e+04
Mean 0.2228
Sigma 19.02
δθ (mrad)
dPhi
Constant 1.003e+04
Mean -10.28
Sigma 17.5
δφ (mrad)
dZ
Constant 1.004e+04
Mean -3.38e-05
Sigma 0.07799
δZ (mm)


ratio_to_thrown
pt (GeV/c)
3-σ dPt: 92.6%
3-σ dPt & dθ: 91.2%
3-σ dPt & dθ & dφ: 90.4%

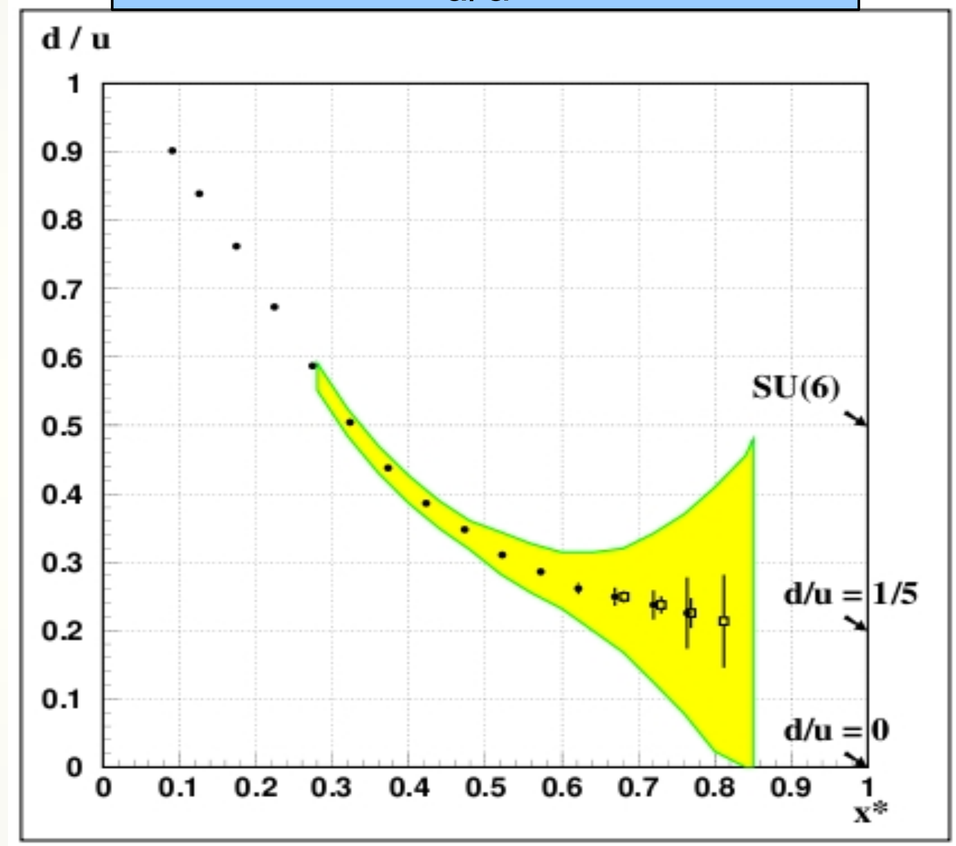

θv [deg]
zv [mm]

Expected Results

Neutron/Proton structure function



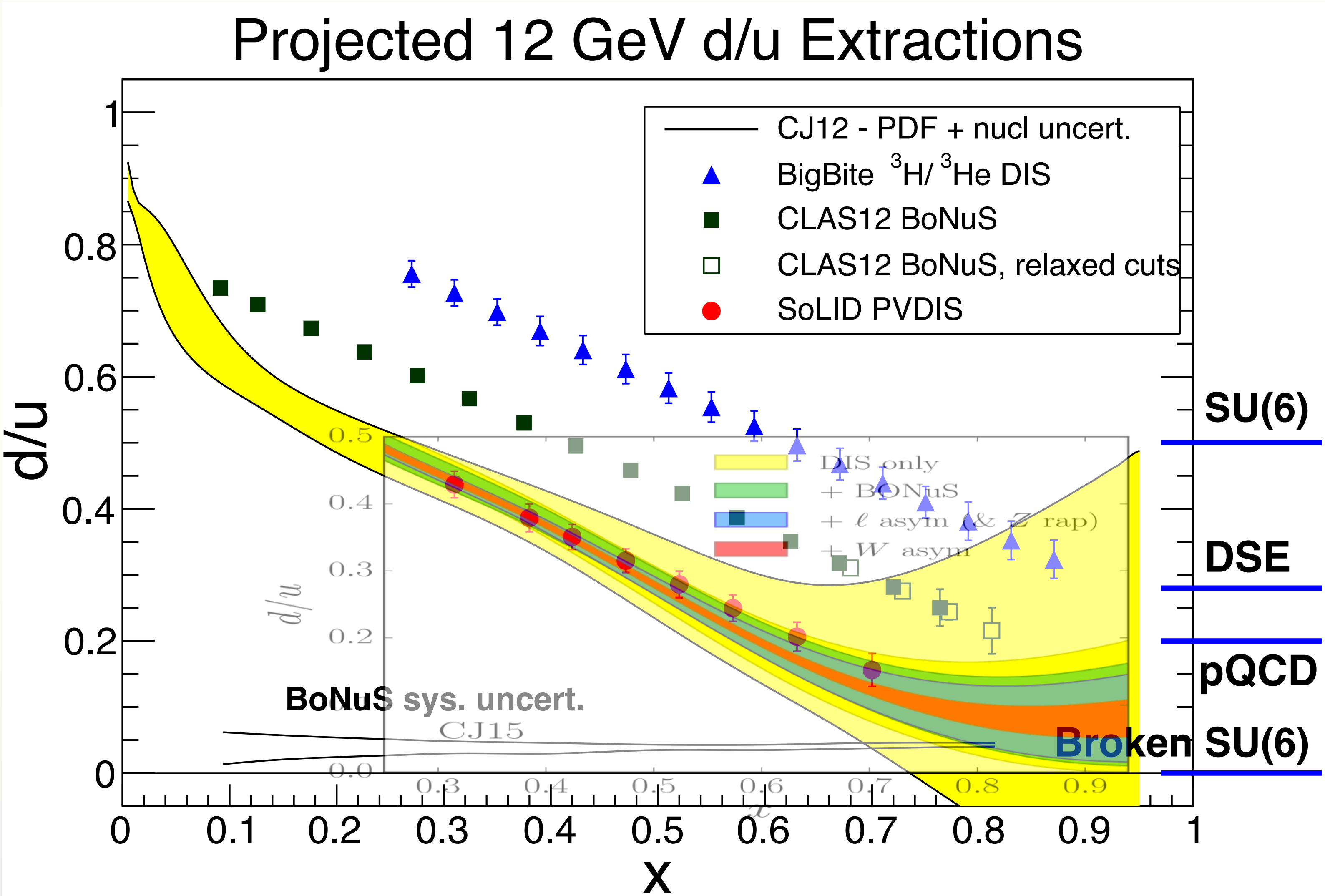
d/u



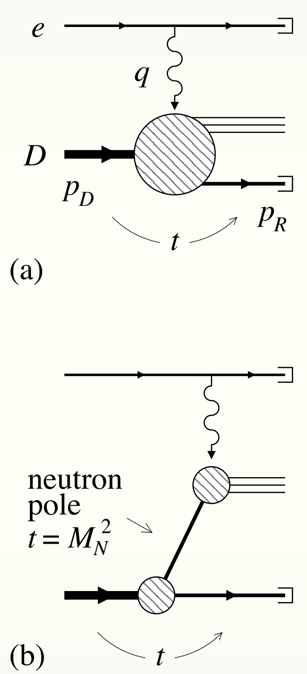
Dark Symbols: W* > 2 GeV (x* up to 0.8, bin centered x* = 0.76)

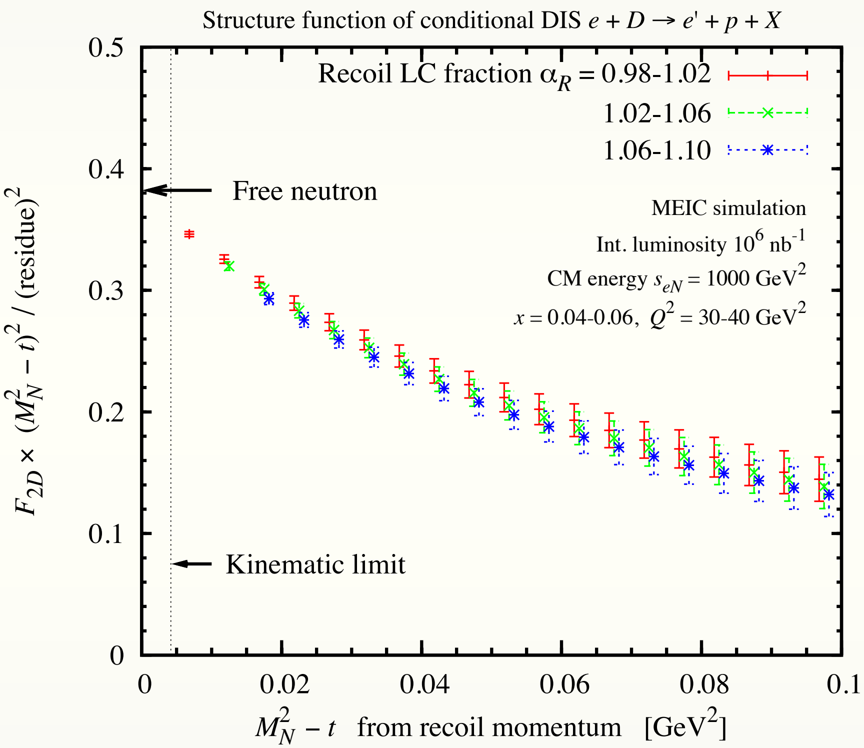
Open Symbols: “Relaxed cut” W* > 1.8 GeV (x* up to 0.83)

The future: JLab at 11 GeV

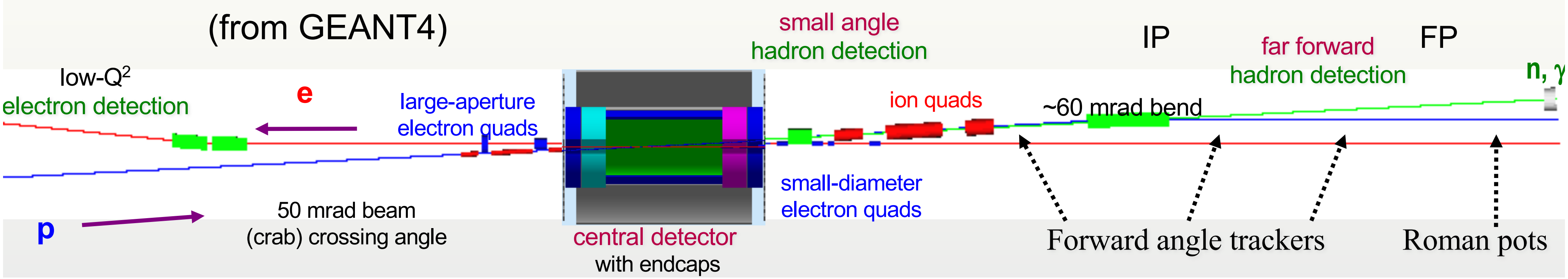


The more distant future: EIC





(from GEANT4)



What else can we do with RG F?

- EMC effect in D
  - tag on slow/fast p; bench mark for heavier nuclei? FSI, d WF,…
- "LAND" experiment E12-11-003A
  - tag p structure in d with backward n (Approved Run Group proposal, PAC43; Or Hen, L. Weinstein, E. Piasetzky, H. Hakobyan)
- nDVCS?
  - At least calibrate CND and get first sample without nuclear distortions; fully exclusive!
- n Form Factors? Alternative method to cross check
- n resonances? (Use forward tagger)
- n SIDIS? (Flavor tagging, TMDs)
- phi-N bound state: Au(γ^*,pK^+K^-)

Summary

- BONuS12 will determine *d*/*u* out to *x* = 0.8 -> high priority
- Present goal: 3rd experiment after LH_2 and LD_2 target (Run Group F, Winter 2019? Passed initial ERR)
- Plethora of potential additional Physics topics
- Detector/target system design at advanced stage

	Activity Name	Resources Assigned	Duration (Weeks)	Start Date	% Done	Finish Date
1	Milestones					
2	Readiness Review		0.0	5/31/17	100%	5/31/17
3	Schedule Request		0.0	7/3/17	0%	7/3/17
4	Schedule Released by JLab		0.0	10/2/17	0%	10/2/17
5	All BONuS Equipment Ready to Install		0.0	12/28/18	0%	12/28/18
6	Float		13.0	10/1/18	0%	12/28/18
7	Detailed Design		**63.0**	**4/3/17**	**37%**	**6/15/18**
8	RTPC		**30.0**	**4/3/17**	**54%**	**10/27/17**
9	*GEM Assembly*	HU, M. Zarecky	26.0	4/3/17	75%	9/29/17
10	*Mandrels*	HU, M. Zarecky	21.4	6/1/17	25%	10/27/17
11	*Drift Region (Cathode, Ground foil)*	HU, M. Zarecky, W&M	28.0	4/3/17	50%	10/13/17
12	*RTPC frame*	HU, M. Zarecky	28.0	4/3/17	60%	10/13/17
13	Target	M. Zarekcy, ODU, R. Miller	39.0	4/3/17	50%	12/29/17
14	Ancillary Systems		**63.0**	**4/3/17**	**30%**	**6/15/18**
15	*Drift gas system (design and build)*	VUU, W&M	51.0	4/3/17	25%	3/23/18
16	*DMS (drift gas monitor system; design and build)*	ODU, VUU	63.0	4/3/17	25%	6/15/18
17	*HV supplies (design and purchase)*	ODU	26.0	4/3/17	50%	9/29/17
18	Slow Controls	VCU, VUU, W&M, W. Moore	52.0	4/3/17	25%	3/30/18
19	Electronics		**39.0**	**4/3/17**	**26%**	**12/29/17**
20	*Padboard design, connectors*	C. Cuevas, HU, J. Wilson, ODU	30.0	4/3/17	30%	10/27/17
21	*Signal translation/circuit-protection boards*	C. Cuevas, HU, J. Wilson, ODU	39.0	4/3/17	25%	12/29/17
22	*Cabling*	HU, ODU, Saclay	39.0	4/3/17	25%	12/29/17
23	Integration		**39.0**	**4/3/17**	**39%**	**12/29/17**
24	*Cart brace and electronics tube attachment*	M. Zarecky, ODU	34.0	4/3/17	50%	11/24/17
25	*RTPC holder*	M. Zarecky, ODU	34.0	4/3/17	50%	11/24/17
26	*Fwd MM Vtx detector holder/cable router*	M. Zarecky, ODU	34.0	4/3/17	50%	11/24/17
27	*Beam line*	M. Zarecky, ODU	39.0	4/3/17	25%	12/29/17
28	*Installation scheme*	M. Zarecky, ODU, Saclay	39.0	4/3/17	25%	12/29/17
29	Construction		**74.0**	**5/1/17**	**5%**	**9/28/18**
30	GEM Assembly		**39.6**	**5/1/17**	**25%**	**1/31/18**
31	*Build GEM foils*	CERN	11.0	5/1/17	75%	7/14/17
32	*Test HV, optical scan, characterize all GEMs*	ODU	8.6	7/17/17	0%	9/13/17
33	*Build individual cylinders*	HU, ODU, W&M	5.0	10/30/17	0%	12/1/17
34	*Assemble with chamfer plate*	HU, ODU, W&M	4.3	12/4/17	0%	1/2/18
35	*Test final Assembly*	HU, ODU, W&M	4.3	1/2/18	0%	1/31/18
36	Rest of RTPC		**47.6**	**11/1/17**	**0%**	**9/28/18**
37	*Procure and build all RTPC parts*	JLab Machine Shop	14.0	11/1/17	0%	2/6/18
38	*Assemble 1st RTPC*	HU, ODU	20.6	2/7/18	0%	6/29/18
39	*Build Integration parts*	JLab Machine Shop	18.0	1/8/18	0%	5/11/18
40	*Procure electronics boards*		22.0	1/1/18	0%	6/1/18
41	*Cosmic and source tests 1st RTPC*	Collab	8.4	7/2/18	0%	8/29/18
42	*Assemble 2nd RTPC*	HU, ODU	13.0	7/2/18	0%	9/28/18
43	Target		**34.3**	**1/1/18**	**0%**	**8/28/18**
44	*Build complete target*	JLab, ODU	18.0	1/1/18	0%	5/4/18
45	*Tests, final safety review*	JLab, ODU	8.6	5/7/18	0%	7/4/18
46	*Integrate target into RTPC*	JLab, ODU	4.3	7/30/18	0%	8/28/18
47	Data Acquisition		**78.0**	**4/3/17**	**0%**	**9/28/18**
48	Front End Units		**39.0**	**4/3/17**	**0%**	**12/29/17**
49	*Complete tests, develop settings, changeover procedure*	ODU, Saclay	39.0	4/3/17	0%	12/29/17
50	Back End Units		**26.0**	**10/2/17**	**0%**	**3/30/18**
51	*Start BEU Effort*		0.0	10/2/17	0%	10/2/17
52	*Programming*	C. Cuevas, ODU	26.0	10/2/17	0%	3/30/18
53	*Inegration into CLAS12 ROC system, DAQ software*	ODU, S. Boiarinov	26.0	10/2/17	0%	3/30/18
54	Online Monitoring Tools	CLAS CALCOM, ODU	26.0	4/2/18	0%	9/28/18
55	Data Analysis Software		**74.0**	**4/3/17**	**21%**	**8/31/18**
56	Data Processing		**73.0**	**4/3/17**	**36%**	**8/24/18**
57	*RTPC integration into coatjava/HIPO*	N. Harrison, ODU, V. Ziegler	17.0	4/3/17	75%	7/28/17
58	*Signal conversion*	ODU, V. Ziegler	26.0	4/3/17	50%	9/29/17
59	*Pattern recognition, track finding*	J. Zhang, ODU, W&M	37.7	4/3/17	50%	12/21/17
60	*Track fitting*	J. Zhang, ODU, W&M	52.0	4/3/17	50%	3/30/18
61	*Complete analysis chain*	ODU, V. Ziegler	38.0	10/9/17	0%	6/29/18
62	*Complete calibration procedure*	CLAS CALCOM, ODU	73.0	4/3/17	25%	8/24/18
63	Simulation		**74.0**	**4/3/17**	**5%**	**8/31/18**
64	*RTPC integration into GEMC (full .stp file)*	M.Ungaro, ODU	39.0	4/3/17	0%	12/29/17
65	*Single proton simulation*	J. Zhang, ODU	26.0	4/3/17	0%	9/29/17
66	*Signal simulation; close loop with Data Processing (see above)*	M. Ungaro, ODU	26.0	4/3/17	0%	9/29/17
67	*Full event simulation, CED*	ODU	38.0	7/3/17	0%	3/23/18
68	*Background simulation*	ODU, R. Montgomery	52.0	4/3/17	25%	3/30/18
69	*Complete simulation of experiment*	ODU	56.8	8/1/17	0%	8/31/18
70						
71	Installation in Hall (Arbitrary start point; after end of previous experiment and Hall ready)		**7.8** 5.0	**1/1/19** 1/1/19	**0%** 0%	**2/22/19** 2/4/19
72	Remove MVT/SVT cart and bring to EEL		0.8	1/1/19	0%	1/4/19
73	Separate MVT from SVT, store SVT		0.6	1/7/19	0%	1/9/19
74	Disconnect all MVT cables from FEUs, secure		0.4	1/10/19	0%	1/11/19
75	Remove FMVT, remove BMVT and store		1.0	1/14/19	0%	1/18/19
76	Mechanically install all RTPC components and FMVT		1.0	1/21/19	0%	1/25/19
77	Install and test all cables, HV, gas lines		1.0	1/28/19	0%	2/1/19
78	Transport to Hall B, fiducialize, insert and align		1.0	2/4/19	0%	2/8/19
79	Integrate into CLAS12 DAQ, ancillary systems, beam line		1.0	2/11/19	0%	2/15/19
80	Cosmic tests		1.0	2/18/19	0%	2/22/19

Conclusion

- Few-body nuclei (D and ^{3}He) continue to be "neutron targets of choice"
- Interpretation of results complicated by off-shell effects, possible structure modifications and final state interaction…
- …but we can also learn a lot about NN interaction and few-body nuclear structure by studying these effects
- New, more precise theoretical calculations are becoming available and can be tested experimentally
- Spectator tagging allows us to minimize binding effects or study them in detail
- BONuS12 will extract neutron valence quark distributions
- Lots more experiments at 12 GeV! Tag polarized SFs?
- Master of spectator tagging: EIC